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INTERACTIONS AMONG BODY WEIGHT, CARCASS CHARACTERISTICS, OVARIAN TRAITS, AND PHOTOPERIOD IN FEMALE BROILER BREEDERS

by

©

SIGRID I. BOERSMA

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to the requirements for the degree of Master of Science
in
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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Interactions Among Body Weight, Carcass Characteristics, Photoperiod, and Ovarian Traits in Broiler Breeders submitted by Sigrid I. Boersma in partial fulfillment of the requirements for the degree of Master of Science.

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DEDICATION

This thesis is dedicated to God my Father
who created me as a unique individual
and most graciously blessed me with gifts
so I could carry out this work.

ABSTRACT

Management of female broiler breeders has focused on regulating ovarian function. The effects of day length, body weight (BW) and BW uniformity, breast muscle development and sexual maturity on ovarian function were examined in hens. Exposure to 28 versus 24 hours of day length resulted in an increase in egg weight but a decrease in reproductive function. Providing chicks with a hatching supplement (Oasis ®) for 30 hours after hatching resulted in an increase in BW up to 4 weeks and a decrease in BW uniformity up to 3 weeks of age. Variations in BW affected the timing of sexual maturation. Plasma estradiol-17β concentration increased with comb size and was relative to BW. Carcass conformation (fleshing content and frame size) of low weight pullets was limited at photostimulation (22 wk). Reproductive performance was reduced in breeders that exhibit low and high BW. Data collection of BW and carcass conformation would help indicate optimal photostimulation and benefit reproductive performance.

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Frank left an impression on me when I first met him in Ontario in 1998. A year and a half later I found myself buying a one-way airfare to Edmonton and flying in the cockpit with two rather humorous pilots who entertained me with chicken jokes for the entire journey. Of all the people I know, Frank is probably one of the most enthusiastic in his knowledge of broiler breeders. During this program I could not help but catch some of his contagious energy. I became a better graduate student because Frank had confidence in my abilities. I worked well with Frank's supervision because he gave me independence in my work and let me show him what I could do.

Technicians, farm laborers, graduate students, research associates and summer students willingly provided me with help when I needed it. During the duration of my projects, Felicity Dennis and Nancy Robinson assisted me with weekly data collection. Their project experience was very helpful. I have fond memories of Nancy, Felicity and I spending time handling birds, recording data or drinking flavored tea together. Other farm staff who kept me on track were Lyle Bouvier, Nigel Davidson, Giles Hinse, Kerry Nadeau, and Shawn Rankin. They showed me that each day should be lived with light heartedness and humor. I'm grateful to Robert Renema, Gaylene Fasenko, Doug Korver, and Martin Zuidhof for their help in the statistical analysis of my data and for reading and editing my papers. Thanks also to fellow graduate students and students

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Although much of my time in Alberta was dedicated to this work, I did have some time to find a wonderful church community who not only supported me with prayer but also with friendship. Their pondering moments of exactly how a person can study chicken reproduction became a Sunday morning routine. I was able to marvel at the sight of Alberta's Rocky Mountains on several occasions. The past two years in Alberta have been an adventure and there is no doubt that this M.Sc. program has well prepared me for my next adventure in life. I look forward to it and will always remember the fond memories of my time at such a great place.

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LIST OF ABREVIATIONS

BW	body weight
CP	crude protein
CV	coefficient of variation
d	day(s)
FSH	follicle stimulating hormone
g	gram(s)
GnRH	gonadotrophin releasing hormone
HIGH	body weight 15 % above standard target weight
h	hour(s)
LH	luteinizing hormone
LOW	body weight 15 % below standard target weight
LWF	large white follicles
LYF	large yellow follicles
ME	metabolizable energy (a calculated value expressed in kcal / kg)
POF	post ovulatory follicles
SM	sexual maturity
STD	standard target body weight
SWF	small yellow follicles
SYF	small yellow follicles
wk	week(s)

1.0 INTRODUCTION

1.1 BACKGROUND

World consumption of poultry products has risen over the past twenty years. Specifically in North America the value of meat-type poultry has increased such that over half of all revenues generated in the poultry industry are contributed from the sale of broiler meat alone (United States Department of Agriculture, 1999 - 2000). This is a positive trend for broiler breeder producers because they provide the supply of broiler chicks to broiler producers. Producers raise broiler chicks and supply chicken meat to the poultry market. More and more consumers prefer breast meat compared to other parts of the processed bird. Breast muscle yield in broilers is strongly influenced by genetics and constitutes the largest amount of their carcass growth (Halvorson and Jacobson, 1970). The parent bird, or broiler breeder, must be effectively managed so to optimize production of eggs and healthy chicks.

Broiler breeders are selected to provide broiler progeny with genetics for high breast muscle yield while sustaining sufficient rates of lay themselves. Breeder companies provide producers with a choice of several different bird strains. Management practices for one stain can not always be directly applied to another. Broiler breeders require a complex system of management because improvements in genetics for growth-type traits have required the need for feed restriction practices in the breeder. A delicate balance between growth and reproductive traits is difficult to achieve because reproductive function and BW negatively correlate (Robinson and Robinson, 1991; Renema et al., 1999). Feed restriction is necessary because growth of the ovary must be managed because of fast growth traits in meat-type birds.

The purpose of this chapter is to review the aspects of reproductive physiology in birds with special emphasis on broiler breeder hens. More specifically, skeletal and muscular growth and the factors that affect sexual maturity (SM) will also be examined. Factors that affect reproductive growth and function in egg producing chickens is undoubtedly not fully understood.

However, domestic birds have a well-structured ovary such that the factors affecting morphological changes of the broiler breeder's ovary can be readily studied.

1.2 REPRODUCTIVE CYCLE OF THE HEN

The Ovary and Follicular Growth

In birds, the ovary is located posterior to the lungs and anterior to the kidneys, on the dorsal wall of the body cavity (Moreng and Avens, 1986). The hen has a single, functional ovary, the left one, and under healthy conditions is able to sustain good egg production throughout life. The domestic fowl (*Gallus domesticus*) is one species whose pattern of follicular development and ovulation is structured within a hierarchy. The ovary contains a complex array of follicles that are classified based on morphology and time to ovulation.

The ovary of the chicken contains approximately one million primordial follicles at hatch (Gilbert et al., 1983). These follicles remain in a resting state until folliculogenesis begins, a process where follicles (< 1 mm) are recruited, selected for further growth and have the potential to dominate over one another so that a distinct hierarchy is established. At SM, the entire follicular makeup includes small white follicles (SWF are < 1 mm) and large white follicles (LWF are 1 - 4 mm) and these follicles constitute the stroma. The remaining anatomy of the ovary includes small yellow follicles (SYF are 5 - 10 mm), large yellow follicles (LYF are > 10 mm), and post-ovulatory follicles (POF) (Etches, 1996b). The most mature follicles, those closest to ovulation, are approximately 5 - 8 in number, where F1 is the designation for the largest follicle followed by the second largest F2 follicle which ovulates 24 - 27 h later, and numbering continues until the smallest large yellow follicle ovulates (Chapeau et al., 1996; Etches, 1996a). After each LYF ovulates, the remaining follicles shift up by one position in the hierarchy. The F1 is approximately 30 mm in diameter before rupture of the stigma after which time it becomes a POF (Volentine et al., 1998). The POF remains attached to the ovary and is reabsorbed within 5 – 7 days (Etches, 1996a).

Reproduction and Biological Rhythms

The reproductive system in avian species is exceptionally sensitive to light stimuli. Birds have an endogenous circadian cycle that is approximately 24 h in length. A wild bird's circadian clock will adjust with natural changes in day length throughout the year. Most birds are long day breeders and the transition from a long day to a short night (dusk) aids in stimulating the reproductive cycle with the aid of the circadian clock. Most intensive poultry operations inhibit birds' natural breeding responses, however, domestic poultry are perceptive to changes in artificial day length. Because birds are naturally sensitive to light, it is very easy to alter the reproductive system by varying the number of light and dark hours in the photoperiod (Zawilska et al., 2000). The photoperiod seems necessary to regulate the function of the hypothalamus and the pineal gland.

Birds are capable of light perception because a neuro-endocrine relationship exists between the brain, pineal gland and retina. The retina synchronizes the circadian system via photoreceptors and ganglion cells that absorb light stimuli and transfer information to the ocular nerve (Moreng and Avens, 1986; Guido et al., 2001). The pineal gland produces melatonin and 5-methoxytryptophol which share an inverse relationship whereby melatonin is secreted during the dark hours and its analog is secreted during light hours (Zawilska et al., 2000). The circadian clock is maintained by rhythmic activity from electrically active cells in the pineal gland (Schenda and Vollrath, 2000). It has been demonstrated *in vivo* that chick pineal mitogen-activated protein kinase shows circadian rhythm in tyrosine phosphorylation (Sanada et al., 2000). The immunoblot assay showed that tyrosine phosphorylation decreases during 12 h of light and increases to peak levels during 12 h of dark. Biological mechanisms in the pineal gland and the retina are important for light perception, yet the hypothalamus is capable of stimulating and maintaining reproductive function without sight. Genetically blind chickens containing the recessive *rc* gene have been shown to maintain adequate production rates, however, Ali and

Cheng (1985) observed that a lack of sight was more associated with a significantly lower fertility rate compared to birds with normal vision.

Egg Production

The rate of egg production in the domestic hen depends on sequence length. A sequence is defined as the number of consecutive days of eggs laid by a hen. Years of domestication have resulted in hens laying nearly an egg a day and result in more than one sequence being laid during the production cycle. A sequence terminates with a pause day or a day in which oviposition does not occur. A pause in oviposition could be due a lack in presence of a mature follicle in the ovary (Williams and Sharp, 1978a) or when a reproductive disorder such as an internal ovulation occurs (Bjerstedt et al., 1995). The first egg within the sequence is usually laid early in the morning and oviposition is successively delayed on each subsequent day in the cycle (Cunningham, 1987). Subsequent delays in a sequence occur because follicles typically do not ovulate every 24 h. Rather, LYF ovulate between 24 - 28 h in a sequence and during a pause day it takes approximately 40 h for the F1 follicle to ovulate (Etches, 1996a).

Nutrition and Reproduction

The complex physiology of reproduction in the hen can be influenced by nutrition. Protein is incorporated in diets at levels that promote skeletal growth and reproductive efficiency. Nutrient composition varies according to growth periods such as the starter, grower, pre-breeder and breeder layer (Leeson and Summers, 2000). A threshold level of protein is required to maintain reproduction during the pre-breeder and layer period. Grimes et al. (1989) fed Hybrid large white turkeys three pre-breeder diets with 12, 15 and 18 % CP from 24 to 32 wk of age. Body weight, age at first egg, egg production, fertility and hatchability were similar between the protein level treatments. It was concluded that any level greater than 12 % does not improve BW and reproductive characteristics in turkeys. Even CP levels as low as 10 % can sustain comparable egg production in broiler breeders compared to 12, 14, 16, or 18 % CP levels (Leeson and Summers, 1997). Fertility rates in the 10 % CP diet were nearly 5 % higher compared to 16 % CP (95.4 % vs. 90.6 %, respectively). The authors suggested that high fertility, achieved in the 10 % treatment, was due to low BW gains between 18 and 60 wk of age. Low levels of CP in the diet may be adequate for maintaining or improving reproduction. However, CP is necessary for muscular growth during the critical periods of growth, and should not be compromised such that levels that depress grow. In general, birds require a range of 15 - 20 % CP for starter, grower or pre-breeder periods (Leeson and Summers, 1997). After lay has commenced the level of CP in the diet is required more for body maintenance than for egg production (Leeson and Summers, 1997).

1.3 HORMONES IN REPRODUCTION

Brain Center Regulation and Control

The physiological aspects of reproduction are regulated by signals from the brain, and more specifically, from regions within the hypothalamus. The hypothalamus sends pulsatile secretions of gonadatropin releasing hormone (GnRH) to the pituitary via the portal vascular system. The chicken hypothalamus releases luteinizing hormone releasing hormone (cLH-RH-I and cLH-RH-II) necessary for secretions of gonadotrophins, luteinizing hormone (LH) and follicle stimulating hormone (FSH) from the anterior pituitary gland (Hattori et al., 1986). This gland is located at the base of the brain and behind the optic nerve (Moreng and Avens, 1986). The chicken pituitary gland has been shown to produce LH and FSH from separate cells within the pituitary gland. Proudman et al. (1999) used a fluorescent dual-label immunohistochemistry technique and identified that LH and FSH are rarely secreted from the same gonadotroph cells in either meat or egg-type chickens.

Regulation of Follicular Growth and Ovulation

Both LH and FSH are glycoproteins which are composed of α and β sub-units and are necessary for gonadotrophin function (Cunningham, 1987). The primary function of FSH is to stimulate the proliferation of small follicles as they enter the ovarian hierarchy. Follicle stimulating hormone is crucial for follicular development. A pre-pubertal rise in FSH is exhibited in broiler breeders at approximately 16 wk of age (Bruggeman et al., 1998). Concentrations of FSH increase as layer pullets advanced towards SM (18 - 20 wk of age) and also during egg production (Lewis et al., 1998). In addition, FSH levels linearly increase as hierarchal follicles approach ovulation (Wells et al., 1985).

Near the time of ovulation, FSH levels decline, and LH is secreted and acts directly on the theca and granulosa cells so that estrogen production is carried out (Williams and Sharp, 1978a; Richards et al., 1987). Concentrations of LH shift from basal to peak levels after the onset of the dark period. The onset to dark in commercial poultry facilities facilitates the 'LH open period' in the hen, which is similar to the response that occurs in wild birds after dusk. The 'LH open period' takes place approximately 4 to 11 h after the onset of darkness (Williams and Sharp, 1978a; Johnson and van Tienhoven, 1980). The level of LH surges 6 to 8 h before ovulation and is followed by a dramatic rise in progesterone from the pre-ovulatory follicle (Wilson and Sharp, 1973; Johnson and van Tienhoven, 1980). Johnson and van Tienhoven (1980) also noticed that after the first and second ovulation in a sequence, the LH peak was simultaneously accompanied by a rise in levels of estrogen derivatives such as estrone and estradiol. However, individual birds may express variation in timing of peak levels. A distinct positive feedback relationship occurs between progesterone and LH at the time of the LH surge. Small daily increases in LH stimulate progesterone secretion and further promote the LH surge, as evidenced by increased production of progesterone when LHRH is injected into mature hens (Etches and Cunningham, 1976; Johnson and van Tienhoven, 1980; Johnson et al., 1985). In the same manner, injection of endogenous progesterone also induces an LH surge indicating that progesterone is a stimulatory hormone for ovulation (Wilson and Sharp, 1976). Circulating testosterone peaks 2 to 4 h before LH and progesterone levels peak but are less direct in stimulating the events of ovulation. Even though testosterone may facilitate the production or release of other hormones, it does not consistently induce ovulation when injected into the chicken brain (Johnson and van Tienhoven, 1980). It is not clear whether LH or progesterone levels peak first during the cycle. However, what is known is that this endocrine relationship is fundamental for successful ovulation.

The process of atresia is common within the ovary and usually occurs in the pool of undifferentiated small follicles. Before follicles grow to 8 mm in diameter, approximately 20 % degenerate and become reabsorbed by the ovary (Gilbert et al., 1983; Johnson, 1993b). Follicles larger than 5 mm may become atretic but it is well known that follicles greater than 8 mm rarely do. These follicles will successfully grow and ovulate unless there are insufficient levels of LH present to induce ovulation (Gilbert et al., 1983). It is unknown why some follicles undergo atresia while others continue to grow and ovulate. Johnson (1996) suggested that the granulosa cells of preovulatory follicles may develop resistance to atresia. Armstrong (1987) found that ornithine decarboxylase enzyme activity is more abundant as follicles increased in weight (up to 250 mg). This enzymatic activity is most notable in small follicles closest to the LYF and LYF stalks suggesting that the location of small follicles attached to the ovary is critical to their fate.

Inhibin is a protein hormone that may play a role in regulating the morphological and physiological distinction between ovarian follicles. The highest production of inhibin originates from the granulosa cells of the ovulatory follicle. Many studies have used the method of ovarianectomy, where the LYF and SYF are removed from hens, and the concentration of the hormone in interest is measured from blood plasma. The level of intensity of inhibin progressively declines as an increasing number of follicles are removed from the hierarchy (Vanmontfort et al., 1992; Johnson, 1993b; Johnson et al., 1993) but more drastically declines when all LYF are removed at once (Bruggeman et al., 1998). Not surprising then is that levels of

FSH successively rise *in vivo* and *in vitro* as the source of inhibin is removed (Akashiba et al., 1988; Johnson, 1993a; Johnson et al., 1993). Whereas LH production is less affected by circulating inhibin, progesterone levels increase in the same manner as FSH (Vanmontfort et al., 1992). Regulatory action of inhibin is presumably due to more than one preovulatory follicle contributing inhibin levels in the ovary.

Steroid Hormone Production

Small yellow follicles are organized so that each follicle is comprised of both theca and granulosa cell layers. Both theca and granulosa cells are separated by a basement membrane where the theca cell layer is the outermost group of cells in the follicle surrounding the granulosa layer (Etches, 1996b). The theca contains two tissue layers. The theca interna is a layer of cells closest to the granulosa layer and the theca externa is a layer of cells located around the outside of each follicle. Both theca layers produce steroid hormones, but the externa layer contains aromatase cells which strictly produce estrogen, whereas the interna layer produces androgens, progestins and estrogen (Nitta et al., 1991). Theca cells contain a large network of capillaries and give the yellow follicles a highly vascularized appearance. This capillary network is the transport pathway required for yolk formation in the yellow follicles.

Follicle size is not always linearly related to the production of steroid hormones. Follicles less than 10 mm in diameter produce large amounts of steroid hormones. Small follicles are highly sensitive to endogenous pregnenolone injections and immediately produce hormones such as estrogen and testosterone in a dose-dependent fashion (Lee and Bahr, 1994). It is the theca tissue in the cohort of the small pre-hierarchal follicles that is steroidogenically active and is primarily responsible for the production of estrogen, androstenedione, and dehydroepiandrosterone (Robinson and Etches, 1986). Granulosa cells (6 - 8 mm) lack the expression of cytochrome P450 enzymes, a pertinent requirement for steroid synthesis (Nitta et al., 1991; Tilly et al., 1991). Sensitivity to LH receptor mRNA activity is not expressed in these cells until the follicle reaches a size of 9 - 12 mm (Tilly et al., 1991) or larger (Nitta et al., 1991; Johnson, 1996).

Hormones produced by the small follicles are strongly influenced by gonadotrophin LH. Johnson (1996) showed that theca cells have an affinity for the LH receptor, as a result of enzymatic activity from cytochrome P450 side-chain cleavage and its counterpart, P450 17α-hydroxylase (Johnson, 1996). Robinson and Etches (1986) further demonstrated that SWF (< 1 mm), LWF (2 – 4 mm) and SYF produce a significantly higher amount of steroid hormones when they are incubated in the presence of LH. Steroid production from the small follicles seems to have an influential effect on the rate of follicular growth and ovulation in the hen. This is a fundamental step in maintaining and providing a steady supply of follicles that have the potential to grow and ovulate.

Estrogen production is carried out by cholesterol side-chain cleavage enzyme (P450 SSC) located in lipid portions of follicular cells (Shoham and Schachter, 1996). Enzyme P450 aromatase has also been located in the theca cells of SYF (Nitta et al., 1991) whereby androgens such as androstenedione and testosterone are necessary precursors for estrogen production (Shoham and Schachter, 1996). A negative feedback relationship between estrogen and the hypothalamus helps regulate gonadotrophin release from the pituitary (Shoham and Schachter, 1996). The concomitant secretion of estrogen from the theca cells is indicative for lipogenesis, albumen, and calcium production during egg and shell formation (Nitta et al., 1991). Shortly before the first egg is laid in a sequence estrogen levels peak (> 250 pg / ml) and sequentially decrease by approximately 30 % to a constant level until a pause day (Bacon et al., 1980).

The level of estrogen that is produced by the small follicles may be influenced by the circulating gonadotrophins. An *in vitro* experiment performed by Robinson and Etches (1986) revealed that estradiol significantly increases in the presence of 6.25 ng of LH in SYF, LWF and LYF, an indication that all the follicles in the ovary contain LH receptors. As follicles are recruited to the hierarchy and approach ovulation, theca cells become decreasingly sensitive to circulating LH, which is apparent because of reduced aromatase activity in these cells (Armstrong, 1994). Furthermore, the production of estrogen by the theca layer of the ovulatory follicle decreases as it matures (Robinson and Etches, 1986; Johnson et al., 1987). Injecting high levels of FSH was necessary to linearly increase estradiol concentrations (Palmer and Bahr, 1992). In contrast, granulosa cells within the F1 follicle are responsive to circulating gonadotrophins and the level of progesterone increases by the presence of LH and FSH (Bahr et al., 1983; Robinson and Etches, 1986).

Ovulation rates are generally controlled by the amount of circulating progesterone. Progesterone production is dependent upon the conversion of 3β-hydroxysteroid to 3-ketosteroid in preovulatory follicles and this action shifts in location from theca cells of small follicles to the granulosa cells of large follicles (Johnson et al., 1987; Nitta et al., 1993). As the bird approaches SM, progesterone levels begin to rise because the granulosa cells become better producers of progesterone and androstenedione. It was originally postulated that the ovulatory follicle is the sole producer of progesterone, and in the presence of the LH surge, the follicle accumulates appropriate levels approximately 6 h before ovulation (Shahabi et al., 1975). Further research has shown that this hormone could be produced by more than one follicle. Even though the ovulatory follicle produces the highest concentration of progesterone, it should be noted that the F2, F3, and F4 follicles also produce this hormone but in smaller quantities (Vanmontfort et al., 1992). In addition, the concentration of LH is higher in the F1 followed by a lower level in the F2 follicle (Wells et al., 1985) and this may be a contributing factor to the production of progesterone within these follicles. Progesterone receptors have also been located in the POF suggesting that the POF may participate in the events of ovulation (Yoshimura and Bahr, 1990). However, the POF is reabsorbed by the ovary and does not receive blood through circulation and could imply an endogenous supply of progesterone rather than the production of it.

The Importance of Growth Factors

Growth factors such as epidermal growth factor (EGF), transforming growth factor (TGF) and those in the insulin-like growth factor family (IGF I and II) are necessary components for reproductive development. The specific functions of each growth factor are not clear. *In vitro*, TGFα was located in the theca interna of chicken follicles and was less effective for promoting follicular growth than EGF (Onagbesan et al., 1994; Volentine et al., 1998). Epidermal growth factor (EGF) receptors have been found in the germinal disc region and surrounding granulosa cells with immunostaining (Volentine et al., 1998) and radioimmunoassay (Humphrey and Bahr, 2001) techniques. It could be stated that EGF acts in a paracrine manner because EGF mRNA were located in both the germinal disc and in granulosa cells and proliferation of granulosa cells occurred in the presence of EGF (Humphrey and Bahr, 2001). In contrast, Onagbesan et al. (1994) found that EGF proliferated the growth of preovulatory follicles in both granulosa and theca tissue, however, the presence of EGF receptors was less intense in the LYF compared to SYF. These data suggest that as the follicle matures, the role of EGF becomes less important. Even though EGF has been shown to initiate the production of granulosa cells, Pulley and Morrone (1986) found that granulosa cells are less apt to produce progesterone in the presence of high levels of EGF (1000 - 4000 ng / mL) in a dose-and time-dependent manner. The circulating action of progesterone was inhibited rather than 3β - HSD activity, which is necessary for the conversion of pregnenolone to progesterone.

1.4 THE ONSET TO SEXUAL MATURITY

Photostimulation of the Reproductive System

The ovary is remarkably small before SM but can be stimulated to grow rapidly by an increase in the amount of light hours as well as a high light intensity during the photoperiod. Ovaries from non-laying hens weigh as little as 7 to 19 g (Kawashima et al., 1992) compared to a range between 50 and 60 g in sexually mature broiler breeders (Robinson et al., 1998a). The ovary will still grow without an increase in the number of light hours and under low light intensity, however, growth is not as rapid. Light intensity as low as 0.05 lux facilitated a reproductive response in some layer strains (Lewis et al., 1999b) which emphasizes how critical a light-tight environment is during the dark hours of the photoperiod. After photostimulation, SM was promoted by 9 d with the use of a 500 lux compared to 1 lux light intensity and a shorter number of light hours (12 h compared to 16 h) delayed SM in broiler breeders (Luzi et al., 2000). However, modern and antique layer strains showed no difference in days to SM with light intensity treatments of 1, 5, 50 and 500 lux (Renema et al., 2001). In the latter study, light intensity had more of an effect on reproductive organs. Oviduct weight, expressed as a percent of BW, was slightly lower in the 1-lux treatment. The ovaries from birds in the 1 lux treatment were approximately 10 g lower in weight than the ovaries from birds in the 50 or 500 lux treatments.

Commercial management requires that broiler breeder pullets be photostimulated between 20 and 22 wk of age, prior to which they usually have a photoperiod of 8 h light and 16 h dark. At photostimulation, light hours are extended to between 14 and 16 h (Pinchasov et al., 1993; Robinson et al., 1998b) and the first egg is usually laid approximately 2 wk later. The photoperiod must be increased for commercial hens. Reducing the photoperiod negatively affects the concentration of gonadotrophins. When the photoperiod is reduced from 14 to 8 h of light at 35 or 56 days of age in a brown egg layer strain, LH and FSH concentrations decreased light (Lewis et al., 1998). The age at first egg (sexual maturity) was delayed by 2 wk compared to 8 h of light. It is clear that photostimulation has a powerful influence on reproductive performance of the domestic hen.

The relationship between physiological growth of the ovary and growth of the rest of the bird has yet to be determined. Understanding this relationship is essential to optimizing reproductive attributes, such as egg production rates, in broiler breeders. Sexual maturity is defined as the time when the ovary is competent to produce eggs. Based on previous research, the timing of SM may be influenced by several factors. Some report that the timing of sexual maturation could be affected by 'thresholds' in BW (Brody et al., 1984; Soller et al., 1984) or fatness (Bornstein et al., 1984). Robinson et al. (1998a) reported a smaller ovary at SM if broiler breeders are underweight, indicating that ovary weight could be compromised if a minimal body weight is not achieved before photostimulation. Luteinizing hormone and FSH levels have also been studied but have shown to be inaccurate predictors of SM because these gonadotrophins, along with photoperiod changes and the age at first egg, do not demonstrate strong and consistent relationships with one another (Lewis et al., 1998; 1999a).

Lack of a common definition has contributed to difficulty in comparing literature related to pullet SM. Kwakkel et al. (1995) introduced a multiphasic model used to describe the relationship between carcass and reproductive growth. A growth spurt, as evidenced by BW gain, generally occurs simultaneously with the growth of reproductive organs. Lewis et al. (1998;1999a) was unable to relate SM to endocrine factors but it may be possible that SM is rather complex and growth of the reproductive system is affected by a myriad of factors. These factors could include body composition and BW, body conformation and a threshold level of gonadotrophins and steroid hormones in the ovary.

Development of Secondary Sexual Characteristics

In preparation for egg production, internal development of the ovary and oviduct is naturally accompanied by the growth of external physical characteristics. Circulating estrogen is important to the development of secondary sexual characteristics in hens and these include comb reddening, feather and medullary growth and widening of pelvic bones in preparation for oviposition (Etches, 1996b). Concentrations of LH and estrogen (Yoav et al., 1998) peak 3 - 5 wk before the first egg is laid whereas progesterone does not rise until 1 wk before SM (Etches, 1996a). Both layer and broiler comb size increase approximately 8 wk before SM where birds fed *ad libitum* finish comb growth before restricted birds (Eitan et al., 1998). Sexual characteristics may be important external indicators of reproductive maturity in birds as a similar appearance between breeders within the same flock may be the best indication that internal reproductive growth and condition is also similar. Little to no variation between birds in the same flock is desirable, especially near SM and before photostimulation, so that physiological growth of the ovary is presumably similar between birds and consequently optimized as a flock.

1.5 FEED PROGRAMS FOR BROILER BREEDERS

Managing the Ovary with the use of Feed Programs

Intense selection of broiler breeder lines has developed a faster growing meat bird and contributes to overall changes in ovarian function. Hocking and Robertson (2000) demonstrated that selection programs have increased the position and the number of LYF in the ovarian hierarchy by approximately two more follicles. For example, 6.5 LYF were reported in non-selected lines compared to 8.3 LYF in contemporary lines over the past twenty years. This is an important event in domestic chicken reproduction because increases in the number of LYF contribute to increases in egg production.

Feeding broiler breeders *ad libitum* has an opposite effect on the ovary compared to the same feeding practice used for modern egg-type strains. This is because genetic programs of the broiler breeder focus more on meat yield and less on egg production. Improvements in breeder genetics have led to the production of broiler progeny that are efficient feed converters. Feed restriction, then, is a necessary practice for broiler breeders in order to manage the growth of the ovary. Ovaries from birds fed *ad libitum* were approximately 48 % heavier than ovaries from birds that are feed restricted (Yu et al., 1992). Feed restriction is also a better method of controlling the number of LYF in the ovary than to *ad libitum* feeding. Hocking (1996) showed a direct linear relationship between BW of breeders and the number of healthy yellow follicles contained in the ovary. In addition, average LYF weight was 13.5 g compared to 10.5 g in birds fed *ad libitum* versus birds experiencing 40 % feed restriction (Hocking, 1996). Increased ovary weight is the result of increased numbers of LYF. Ten compared with eight LYF have been reported in breeders fed *ad libitum* or restriction diets until 47 wk of age, respectively (Waddington and Hocking, 1993). Similarly, Yu et al., (1992) showed that broiler breeders on a full fed diet from 18 to 62 wk of age had 12.2 large yellow follicles compared to 7.8 in restricted birds during the same time period.

Abnormally large numbers of similar sized LYF in the ovary is an indication that reproductive problems are likely to occur. Incidences such as erratic laying patterns, poor quality shells, and a higher number of multiple yolks (paired LYF) contribute to an inefficient laying breeder (Yu et al., 1992; Robinson et al., 1993; Hocking, 1993). The incidence of such problems could be as high as 18 - 40 % in overweight birds (Yu et al., 1992). Shorter sequences, higher embryonic mortality (Robinson et al., 1993) and shorter periods of fertility (Goerzen et al., 1996) have also been exhibited in obese broiler breeder hens.

The incidence of atresia seems more prevalent in obese birds compared to lean birds. The number of atretic follicles (< 3.2 mm) correlated with the amount of very low density lipoproteins (VLDL) and the amount of VLDL is higher in obese birds (Hocking and Whitehead, 1990). Leaner birds produce more white follicles and fewer of these follicles undergo atresia, which may indicate that successful growth of small follicles is dependent upon the amount of adipose tissue (Hocking and Whitehead, 1990). Anomalous reproductive attributes examined in this section are detrimental to the overall reproductive capability of the hen.

The type of feeding program also has a substantial effect on days to SM. It has been clearly demonstrated that that feed restriction, in contrast to *ad libitum* feeding, delays the onset of the first egg (Hocking and Whitehead, 1990; Hocking, 1996; Robinson et al., 1998b; Robsinson et al., 1998c; Hocking and Robertson, 2000). Specifically, Renema et al. (1999) reported a delay from 25.3 d after photostimulation to 38.9 d in restricted broiler breeders. A*d* *libitum* feeding has been found to promote reproductive maturity even before photostimulation (Hocking, 1993). Robinson et al. (1998b; 1998c) tested daily feed allotments (slow fed) versus weekly feed allotments (fast fed) and found that fast fed birds came into production an average of 0.5 - 1.9 d sooner. In contrast, Yu et al. (1992) provided *ad libitum* food from 18 wk of age and found that even though ovary weight and follicle number increased, the age at first egg was unaffected. However, strain may affect the age at first egg in response to a photostimulatory cue (Robinson et al., 1998c).

An increase in the emphasis of meat yield in commercial broiler breeders could possibly desensitize the ovary in its response to restrictive feeding. Hocking and Robertson (2000) have recently suggested that feed restriction in highly selected breeders is less effectively controlling reproductive parameters within the ovary than in breeders who undergo less intense selection for growth traits. This was especially evident when the number of multiple ovulations was prominently higher in contemporary versus unselected lines. Multiple ovulation is caused when two follicles ovulate from the ovary in rapid succession and produce a double yolk egg. The ovary seems less sensitive to the production of LH regardless of the feed program whereas a rise in LYF numbers is most likely due to a higher production of FSH by the ovary and is encouraged by an *ad libitum* feed program (Bruggeman et al., 1998). More emphasis in current research should be placed on managing the ovary. It would be an enormous loss if the broiler breeder's ovarian sensitivity and natural physiological responses to reproduction were negatively altered as a result of intense selection programs.

1.6 BODY WEIGHT AND MORPHOMETRICS

Body size, BW and BW gain in meat-type chickens are controlled by many different factors. It is crucial that birds receive both food and water immediately after hatch. Previous research has demonstrated that post hatch delays caused long term and even irreversible negative effects on body weight and BW gain in broiler chicks (Pinchasov and Noy, 1993; Vierra and

Moran, 1999). A post hatch delay from the time of hatching to placement is inevitable because birds must be processed at the hatchery before they are shipped to the farm. However, the negative effects on BW can be bypassed by administrating a hatching supplement during this time (Noy and Pinchasov 1993; Noy and Sklan, 1999). Other factors that affect BW include protein intake (Peak et al., 2000), energy intake (Hudson et al., 2000), qualitative feeding (Zuidhof et al., 1995) or the amount of feed (Bartov and Wax, 1998; Renema et al., 1999).

Body Weight Uniformity

The pullet BW of broiler breeders is maintained by allocating feed according to target BW growth curves provided by a breeder company. Body weight uniformity can be expressed as both the coefficient of variation (CV) and the percent of birds that are within ± 10 or ± 15 % of the flock mean. The CV calculates BW uniformity for the whole flock, including birds that are under or over weight from the target mean. The CV may be more easily confounded BW of birds that are too light or too heavy. Calculating the percent of pullets that are ± 10 or ± 15 % within the flock mean expresses the number of birds that are near the ideal BW. The latter method of calculating BW uniformity is more common in North America than the CV. A highly uniform flock, or a flock with a high percentage of pullets close to the target average BW, ensures that most birds are receiving optimal nutrient allocation.

Flock uniformity is important in broiler breeder pullets because a more uniform flock could have a larger percentage of the birds responding optimally to light programs at SM. There is a limited amount of published work that shows the implications of variable uniformity as birds approach SM or after this time. Akanbi and Goodman (1982) improved BW uniformity in Hisex Leghorns by sorting according to BW at 9 wk of age, but this practice did not significantly affect egg production. In the broiler breeder industry, producers typically attempt to attain 80 %

uniformity assessed by using ± 15 % of the flock average, unfortunately, a lower uniformity is often achieved.

Several management techniques have been shown to increase BW uniformity. Body weight uniformity improved (89 % of flock within ± 10 % of the mean) when broiler breeders were divided into three weight classes of light, middle and heavy and resorted at 4, 8, 12, 16, and 20 wk of age compared to a control flock of broiler breeders that was not sorted during the rearing period (Pettite et al., 1981). Birds in the heaviest, middle and lightest BW treatment group were fed a 13, 15, and 17 %, respectively, compared to the control birds that were fed a diet composed of 15 % CP. Zuidhof et al. (1995) added 15 or 30 kg of ground oat hulls to 85 and 70 kg of a standard broiler breeder diet, respectively, and found that uniformity (CV) was the best in the 30 kg treatment. Feed dilution increases feed clean up time and demonstrates that nutrient dilution has a positive effect on flock uniformity (CV). In contrast Pinchasov et al. (1993) showed that qualitative restriction methods such as supplementation of proprionic acid or reducing the amount of amino acids in the diet decreases BW uniformity compared to conventional feed restriction (10 % versus 16 % CV, respectively). Body weight uniformity was unaffected from a limited daily restricted or a skip-a-day restricted feed program (Hudson et al., 1999). Others suggest social dominance, rather than the practice of feed restriction, may negatively affect uniformity (Leeson and Summers, 1979). From this research it is evident that uniformity can be affected by several different management practices and perhaps establishing good, consistent uniformity is achieved with a multi-factor management approach.

Importance of Skeletal and Muscular Morphology

Skeletal and muscular composition are pertinent aspects to BW and reproduction in broiler breeder hens. A vast amount of research has discussed the implications of BW on reproductive characteristics but little published work is available on the relationship between bird morphology, SM and subsequent egg production. Finding a strong correlation between morphology and SM could influence the refinement of current management practices for breeders. These practices chiefly include time of photostimulation because muscle development is a necessary component of carcass growth and should be near completion before the onset to reproductive maturity.

Calculating BW uniformity has been a common method used to indicate the number of birds that are within an acceptable BW range from the recommended BW target. However, a uniformity value based on BW does not provide information on body frame differences within a flock. It is possible that birds with varying frame size may show different reproductive responses to feed allocation and photostimulation. For example, a large framed and underweight bird would unlikely finish muscle growth before photostimulation is imposed in comparison to a smaller framed bird. A well-fleshed bird generally has adequate muscle coverage in relation to its skeletal development and may typically be a more efficient reproducer (Don Copeland, Aviagen North America, Huntsville, Alabama, 35805, Personal Communication, 2001). Photostimulation at a later age (22 wk) caused birds to allocate nutrient resources in preparation for SM as opposed to breast muscle deposition (Joseph, 2000). Having said this, a smaller-framed bird may reach SM at a slower rate and during production may continue to allocate nutrient resources to both reproduction and growth. Renema et al. (1999) selected pullets after feed restriction during rearing and subsequently fed the birds relative to their body weight gains. Light birds required 8.5 d more to reach SM compared to birds that were fed according to a target body weight curve. Similarly, birds with high body weight required 7.6 d less to sexually mature. Overall there was no effect on the number of atretic follicles, normal follicles, unexplained POF, multiple ovulations and ovary weight between the light, medium or heavy birds.

Maximal growth of muscle is largely dependent upon the genetic makeup of the bird. The growth potential of muscle is related to the amount of DNA within the muscle (Smith, 1963). The maximum growth of muscle can vary between strains because the amount of total DNA varies from strain to strain, however, total DNA also increases with age (Acar et al., 1993). Currently, broiler breeder selection programs focus on breast muscle fleshing and are largely based on manual palpation to assess the amount of muscle surrounding the sternum in relation to frame size (Don Copeland, Aviagen North America, Huntsville, Alabama, 35805, Personal Communication, 2001). Breast muscle development is an important growth parameter because approximately 15 to 20 % of total BW is attributed to breast weight (Renema et al., 1999) and breast muscle grows in proportion to BW (Etches, 1996b). Breast weight normally includes both the *Pectoralis major* and *Pectoralis minor* muscles. Breast muscle growth is strongly influenced by dietary energy. A diet of 3133 kcal / kg compared to 2885 kcal / kg from 12 to 16 wk of age increased the *Pectoralis major* muscle mass in broiler breeder starter diets (Hudson et al., 2000).

Breast muscle is normally dissected from a chicken so that absolute weight and breast weight relative to BW can be reported as a result of experimental treatments. Although this information is useful for determining strategies for feeding breeders it would be more desirable to maintain similar birds from growth to SM, and through egg production so that breast muscle growth can be monitored during these critical times. Two external indicators (thoracic width and circumference) could provide information for this type of research. A ratio used by one particular breeder company is described as the length:width ratio and includes the keel length and thoracic width (Aviagen North America). Because the thoracic width is measured at the widest part of the breast muscle, this ratio becomes useful in determining muscle development in relation to frame length. High-resolution ultrasound has also been found as a good predictor of breast muscle weight in commercial broilers (Grashorn, 1994; Konig et al., 1998) but not in broiler breeders. Accuracy of ultrasound for measuring breast muscle thickness varies between published research (Konig et al., 1998; Cywa-Benko et al., 1999). Characterizing breast muscle growth by ultrasound measurements could be a useful index for managing birds during the most critical growth period before SM.

Shank (tarsometatarsus) length is defined from the top of the hock joint to the bottom of the footpad. Keel (sternum) length is defined from the top of the clavicle bone to the caudal end of the sternum; this site supports the breast muscle. Skeletal development is rapid in immature birds and is influenced by the level of protein formulated in the diet (Leeson and Summers, 1984). Low protein diets hinder the development of bone structure and size, whereas high protein diets enhance bone development (Leeson and Summers, 1979). Low protein diets hinders the development of bone structure and size, whereas high protein diets enhance bone development (Leeson and Summers, 1979). Leeson and Summers (1984) demonstrated that after 15 wk of age, the correlation between BW and shank length, BW and keel length as well as shank and keel length was not significant. Male Leghorn chicks fed a diet composed of 20 % had longer skeletal frame compared to chicks fed a diet composed of 13 % CP. Similarly, increased inclusion of CP in the diet (12, 16, or 20%) linearly increased shank and keel length but the effect of a high inclusion of CP in the diet diminished by 14 wk of age in female broiler breeders (Hudson et al., 2000). A diet composed of 20 % soy protein significantly increased the length of the shank bone in 14 day-old male Leghorns, compared to feeding chicks a diet composed of 5 % soy protein (Leili and Scanes, 1998). Lilburn et al. (1989) showed that BW and keel length had a high correlation (r =0.63) at 12 wk of age in broiler breeders although a large gain in BW was required to significantly increase the length of the keel bone. In addition keel, shank, tibia, and clavicle length grew longer when birds had a BW that was 30 % above those fed according to the Hubbard Farms broiler breeder management guide. Similarly, Leili et al. (1997) demonstrated that by 16 days of age, the shank bone was 11 mm longer when fast growing male leghorn pullets were fed an *ad libitum* diet versus a 60% reduction from *ad libitum*. These data suggest that long bone growth can be suppressed when birds are feed restricted compared to those given a full allowance of feed.

Previous literature has shown that body weight and skeletal growth was influenced by the composition of the diet. However, growth factors are also essential to the growth composition of a bird. It seems apparent that IGF and their binding proteins are essential to the growth process and relatively responsive to small changes in food programs. Circulating levels of both IGF-I and II decreased and subsequently increased when birds were fasted and re-fed, indicating that IGF is dependent upon feed program (Beccavin et al., 2001). In addition, Leili et al. (1997) reported lower circulatory IGF-I concentration after only a 20 % reduction in food intake from *ad libitum*. Concentrations of IGF-I increased more than IGF-II until 6 wk of age as did IGF mRNA levels after which time no differences were found indicating an age-dependent relationship (Beccavin et al., 2001). Also, birds genotypically selected for high growth had higher concentrations of IGF-I and II compared to those selected for low growth. Levels of IGF-I could be dependent upon protein levels. A 5 % inclusion of soy protein decreased IGF-I compared to a 10 % inclusion level in male Leghorn chicks (Leili and Scanes, 1998).

Both Single Comb White Leghorn and broiler breeder hens had less bone forming cells in the femur after SM rather than before SM (Hudson et al., 1999). Cortex bone formation occurs more actively before SM as opposed to after egg production commenced in Arbor Acres broiler breeders (Hudson et al, 1999). Flourochrome labeling of the femur showed less structural and non-structural bone in sexually mature versus immature Hy-line white layers (Hudson et al., 1993). These data suggest that skeletal growth is less prominent after SM and can be maintained under low protein diets whereas low protein diets before SM could be detrimental to bone growth. Growth factors such as IGF-I and II influence skeletal and body growth where the level of these growth factors is responsive to protein levels or amount of feed consumed. Muscular and skeletal growth have been reported in this section and aside from the detrimental effects of *ad libitum* feeding on ovarian growth, these factors as indicators of reproductive maturity have been given much less attention. Specifically in broiler breeders, relationships between reproductive maturity and external cues such as thoracic width, circumference and comb growth have not yet been established as reliable predictors of SM.

1.7 AGE AND REPRODUCTIVE FUNCTION

It has well been established that reproductive output of the domestic hen declines with advancing age. Reproductive condition is usually defined by egg production rate. However, there are other outcomes involved. Fertility rates have been shown to progressively decline with age (Hocking, 1990) as does mating frequency as natural mating behavior is dependent upon estrogen levels which also decrease with age (Ottinger, 1991). Egg production rates tend to decrease with chronological age as a result of increased intervals between ovulations (Williams and Sharp, 1978a). Shortened sequence lengths and longer pauses between ovipositions are most likely caused by a reduction in pituitary LH, as less frequent signals originate from the hypothalamus (Williams and Sharp, 1978b). Hens at peak egg production have shorter ovulation intervals and require approximately 24-25 h (Etches, 1996a) to lay each egg within a sequence whereas older hens need as long as 40-44 h intervals for adequate egg formation in a sequence (Shanawany, 1992). A slower rate of follicular maturation can lower egg production by approximately 30 % from peak production and onward.

Older chronological aging affects the function of the ovary. Slower follicular maturation rates and an increase in the size of the LYF can occur. Williams and Sharp (1978c) showed that young broiler breeders at their peak egg production produced significantly more LYF than 82 wk old birds with a mean number of seven compared to five, respectively. Conversely, even though older hens produce fewer LYF, these follicles were heavier in weight with 18.3 ± 0.3 g compared to 11.6 ± 0.32 g for younger birds. Therefore, the aging process generally affects birds by causing heavier but fewer eggs later in the egg production cycle. The prehierarchal follicles produce estrogen and production is concurrent to the number of these follicles. Chronological aging tends to linearly decrease the number of small follicles in the ovary (Robinson et al., 1996) because a higher number undergo atresia (Palmer and Bahr, 1992) thereby dramatically decreasing sites for estrogen production. A reduction of 64% fewer SYF and 65% fewer LWF has been found in Single-Comb White Leghorn hens between 80 and 100 wk of age compared to younger hens between 30 and 50 wk of age (Palmer and Bahr, 1992).

The undesirable effects of aging on the reproductive system of the domestic hen may be somewhat minimized if the photoperiod is appropriately altered. A modification from a normal circadian cycle to an ahemeral one could potentially maintain egg production rates for a longer period of time. Most research has shown that total egg production rates decline when ahemeral cycles are implemented in young or old layer flocks, however, an improvement in shell quality is generally seen. Spies et al. (2000) showed that an ahemeral photo schedule of 14L:14D increased egg size but lowered egg production rates for broiler breeders 25 to 29 wk of age. Foster (1968) and Morris (1973) suggested that ahemeral day lengths could possibly entrain or synchronize rate of lay, however, this is usually at the expense of egg production. More positively, ahemeral day lengths increased shell quality with a 14L:14D photoperiod (Leeson et al., 1979) and shell weights with a 16L:12D photoperiod (Nordstrom and Ousterhout, 1983) for white Leghorn hens 62 and 72 wk of age, respectively. It seems evident that a bird's reproductive response is altered when day length is increased, which only confirms how sensitive birds are to alterations in photoperiod.

1.8 CONCLUSIONS

Research cited in this chapter elaborated on the complex interactions between reproductive hormones, reproductive maturation, and the relationship between growth and reproduction in broiler breeder females. The ovary is physiologically receptive to feed programs and photo schedules. Negative effects of high or low BW on reproductive function could be circumvented if management practices focussed more on the critical growth periods of breeders. Very few papers in published literature have focussed on characterizing muscle and skeletal growth (thoracic width and circumference, breast muscle thickness, shank length, keel length and comb size) as a broiler breeder reaches SM. It may also be important to focus on the early stages in life. Extensive transportation times decrease energy reserves in chicks and lower BW, causing a poor start early in life. Increased demand for high quality and quantity of poultry meat will continue. The broiler breeder must then be effectively managed for optimum egg and healthy chick production.

1.9 DESCRIPTION OF EXPERIMENTS

Objectives

These experiments were designed to investigate the interactions between body weight, carcass characteristics, ovarian traits, and photoperiod in broiler breeder females.

Experiments

1. **Purpose:** To examine the effect of extended day length, used to minimize the natural decline in egg production typical of aging birds, on carcass and reproductive parameters.

Description: A 28 h day was used (15L : 13D) between 47 and 55 wk of age. Carcass and reproductive characteristics were determined.

2. **Purpose:** To examine the effects of holding chicks for 30 h post hatch with or without access to the Oasis ® hatching supplement on BW, BW gain and BW uniformity from hatching to 18 wk of age.

Description: Individual BW data were recorded at hatch, 0 wk (hatch + 36 h), weekly from 1- 4 wk and at 8, 12, 16, and 18 wk of age. Body weight uniformity was based on CV and the percent of birds that were within ± 10 or ± 15 % of the flock mean.

3. **Purpose:** To characterize breast muscle development by using conformation measurements, ultrasound and image analysis techniques.

Description: Conformation measurements included keel length, thoracic circumference, and thoracic width. Birds were fed on three feeding programs of STD (target BW), LOW (15 % lighter BW than STD) and HIGH (15 % heavier BW than STD). Ultrasonography was used to measure breast muscle thickness *in vivo*. Birds were killed at 18, 22, and 26 wk of age.

Dissected breast muscles were digitally photographed for characterization by image analysis (length, width, and area).

4. **Purpose**: To examine sexual maturation from three groups of female breeder pullets varying in BW.

Description: Body weight treatment groups were similar to Experiment 3. Weekly live bird measurements of shank, keel, thoracic circumference, thoracic width, and comb size (length, height, and area) were collected from 18 wk of age to SM. Breast muscle thickness, plasma lipid and estradiol-17β were measured in a sub-population of birds. At SM, the ovaries were dissected and follicles were classified by weight and by size. Breast muscle, oviduct, fat pad, and liver were dissected from each bird and weighed.

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2.0 THE EFFECT OF TWENTY-EIGHT-HOUR AHEMERAL DAY LENGTHS ON CARCASS AND REPRODUCTIVE CHARACTERISTICS OF BROILER BREEDER HENS LATE IN LAY

2.1 INTRODUCTION

Reproductive efficiency of broiler breeder hens is strongly influenced by the aging process. A decrease in the rate of egg production and an increase in egg size are generally seen after peak production. Hatching eggs within Alberta are not accepted by commercial hatcheries if they are below 52 g. An increase in egg size may seem beneficial from a hatching egg standpoint but some large eggs cannot properly fit into commercial incubator flats.

It may be possible to enhance reproductive efficiency of broiler breeder hens late in lay by increasing the day length from a normal circadian cycle to a long ahemeral one. Ahemeral day lengths could potentially maintain egg production rates for a longer period of time and reduce age effects. Most research has shown that total egg production rates decline when ahemeral cycles are implemented in young and old layer flocks. Spies et al. (2000) showed that an ahemeral photoschedule of 14L:14D increased egg size but lowered egg production rates for broiler breeders 25 to 29 wk of age. Foster (1968) and Morris (1973) suggested that ahemeral day lengths may possibly be entrained or synchronized with rate of lay. However, this is usually at the expense of egg productivity.

Data are available for old aged egg layer flocks (Leeson et al., 1979; Nordstrom and Ousterhout, 1983) but less frequently for old broiler breeder hens (Shanawany et al., 1993). Generally, ahemeral cycles have been reported to positively affect eggshell quality, but have not improved egg production. Ahemeral day lengths increase shell quality with a 14L:14D photoperiod (Leeson et al., 1979) and shell weights with a 16L:12D photoperiod (Nordstrom and Ousterhout, 1983) for white Leghorn hens at 62 and 72 wk of age, respectively. Some research has shown egg production for older birds to be unaffected by ahemeral day lengths (Leeson et al., 1979; Nordstrom and Ousterhout, 1983; Shanawany et al., 1993).

The objective of this study was to examine the effectiveness of using an extended day length of 28 h on the reproductive efficiency of old broiler breeder hens. It was expected that day length would synchronize with follicular maturation rate in older hens and enhance reproduction. Specifically, enhancements would result in an increase in the number of LYF, ovary, stroma, oviduct weights, as well as enhanced egg production and shell quality, without and increase in egg size over accepted limits for incubation.

2.2 MATERIALS AND METHODS

Stocks and Management

A total of 136 broiler breeder hens from three different genetic strains [1]; Classic, Feather Sexable Yield (FSY), and Experimental (EXP) were used for this trial. The birds were reared in brooder floor pens and individually housed in layer cages at 20 wk of age. Initially, the pullets were part of an experiment in which half were photostimulated at 20 wk and the other half at 23 wk. Age at photostimulation was included in the randomization process for the present study. At 47 wk of age, 128 birds were selected from 136 based on proximity to target BW and egg production level. Birds that were overweight or underweight based on target BW ranges (> 11% overweight and > 14% underweight), from the Arbor Acres Broiler Breeder management guide (Anonymous, 1998), as well as birds with slow egg production rates (less than three eggs per wk) were not selected. Ten to 12 birds were used from each strain and age at photostimulation and placed into each of the two treatment groups (24 h and 28 h day length). The light period remained the same at 15 h per day for both treatment groups, however, the dark period extended from 9 to 13 h for the ahemeral treatment. This experiment was conducted in accordance with the principles and guidelines set by the Canadian Council on Animal Care (Olfert et al., 1993).

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[1] Aviagen North America, Huntsville, AL, USA, 35805.

Housing and Environment Conditions

Birds were individually housed at 47 wk of age in four identical environment chamber rooms until 55 wk of age. Environmental conditions such as temperature, humidity and ventilation were separately controlled for each room. A Phason [2] automatic environment control unit was located on the outside of each room in order to obtain consistency of all environmental parameters such as temperature and ventilation rate. Digital thermometers [3] were placed on the outside of each room as back up to monitor dry-bulb temperatures. Day length was controlled by single channel electronic time controllers [4] and programmed for day length treatments. Broiler breeder hens were individually housed in eight modified battery cage units with sixteen cages per unit, four units per treatment group and two units per room. Cages were equipped with an individual feeder and one nipple drinker was shared between two hens. Light was provided by one incandescent bulb per cage and maintained at 100 lux. Birds were fed a wheat-based breeder layer diet (ME = 2910 kcal / kg, CP = 15.8 %, Ca = 2.96 %).

Eggs were gathered, weighed, graded and recorded for each bird. Eggs were scored for integrity (normal, soft-shelled, membranous, double-yolks, broken, abnormal or pecked). All birds were individually weighed on a weekly basis and feed was allocated based on average weekly weights (Table 2-1). All birds in the ahemeral and hemeral treatments were fed between 126 and 127 g / day. However, due to the long day length in the ahemeral treatment, ahemeral birds were fed six times per week compared to seven times per week for the hemeral treatment. Daily feed allocation was adjusted for the ahemeral treatment so that birds were fed an identical amount of feed per week as the hemeral birds but it was adjusted over six days. All birds were fed between 1.5 and 2.0 h after the lights automatically switched on in the environment chamber rooms.

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[2] Model AEC-2, Phason, Winnipeg, MN, Canada, R3P 2H7.
[3] Model 90278, Springfield Instrument Company, Mississauga, ON, Canada, L5T 1Z3.
[4] Model EC 7005 PC/120, Paragon Electric Company, Two Rivers, WI, USA, 54241.

On the last 3 d of the trial, eggs were collected, weighed, graded and marked according to cage number and placed in cool storage for 3 to 5 d with a temperature range of 13.0 to 15.0 C. On day 5 of storage, stored weights and yolk weights were measured. Shell quality was measured by specific gravity using the flotation method in increments of 0.02 (concentration range from 1.060 to 1.100). Eggs were broken open and yolk was separated from albumen and weighed. The eggshells were washed to remove excess albumen and left to naturally dry upon which dry shell weight was recorded. Albumen weight was calculated from the difference of total stored weight, shell and yolk weights.

The incidence of mortality was monitored throughout the 8 wk period. The ahemeral treatment group lost one bird on d 332 (no visible lesions) and another was culled on d 350 due to a marked decrease in appetite. Similarly, one hen in the hemeral group died on d 350 (no visible lesions). The project terminated on d 390, and each of the 125 broiler breeder hens was killed by cervical dislocation, weighed and dissected. Breast muscle (*Pectoralis major and minor*), liver, fat pad (including fat surrounding the gizzard) and reproductive organs such as the ovary (yellow follicles and stroma), oviduct and shell gland were collected and weighed. The ovary was further analyzed by counting the number of normal and atretic large yellow follicles (LYF are > 10 mm), small yellow follicles (SYF are 5-10 mm), and large white follicles (LWF are 3 - 5 mm). Total follicular weight included the weight of all LYF and omitted any atretic follicles attached to the ovary.

Statistical Analysis

A 2 X 2 X 3 factorial design was used with two day lengths (24 h and 28 h), two ages of photostimulation (20 wk and 23 wk) and three strains (Classic, FSY and EXP). All treatment effects and interactions were tested for significance at the $P < 0.05$ level using the General Linear Models procedure (SAS Institute Inc., 1999). P-values for differences for the LS-means were generated by SAS ® when the main effects or interactions were significant (SAS Institute In., 1999). The highest standard error value was reported for each of day length, strain, photostimulation age and interactions. Egg production was categorized as Period 1, Period 2, and Entire Period in order to determine if an initial reproductive response to the treatments would occur. Temperatures were recorded daily for each room. Temperature data was statistically analyzed on a weekly basis in order to ensure consistent environmental temperatures across the rooms. The average temperature ranged between 18.7 C and 21.4 C and was not statistically different between rooms throughout the treatment period. Least squared mean values for egg weights by treatment group for each week were plotted using SigmaPlot [5].

2.3 RESULTS AND DISCUSSION

Body Weight

There were no significant treatment differences when average weekly BW were examined by day length (Table 2-1) or age at photostimulation (data not shown) as well as the interactions (data not shown). There were significant strain differences in BW between 47 and 55 wk of age with the exception of 50 wk where no differences were found (Table 2-1). Experimental (EXP) birds were significantly heavier than Feather Sexable Yield (FSY) and Classic birds at all ages except at 50 wk of age. Overall, ahemeral day length did not increase BW at each wk or total BW. Even though birds were fed the same type and amount of feed, the EXP birds maintained a significantly higher BW than Classic birds. This was most likely due to differences in growth capabilities between the strains.

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[5] SigmaPlot for Windows Version 3.03, Jandel Corporation, San Rafael, CA, USA, 94912.

Egg Weights and Production Levels

The effect of day length and strain on egg weights and egg production levels are shown in Table 2-2. Overall, ahemeral treatment significantly increased egg weight by 1.67 g. Mean values for egg weight for the ahemeral group increased rapidly during 47 - 48 wk and reached a maximum at 53 wk (Figure 2-1). Hemeral birds showed a rapid increase in egg weight from 47 to 48 wk of age. This finding is consistent with Nordstrom (1982) and Leeson et al. (1979) who found significant increases in egg weight 1 to 2 wk after the onset of 27 h and 28 h treatments, respectively. Previous research has shown that albumen and yolk weights increase linearly with increasing day length (Leeson et al., 1979; Shanawany et al., 1993). However, results in the current study do not support this (Table 2-3). In this trial, photostimulation at 23 wk of age increased egg weight (*P* = 0.02). Melek et al. (1973) demonstrated that a 27 h day length increased the length of time egg spend in the shell gland but not in the infundibulum, magnum, or isthmus. A calculation by regression equation demonstrated that eggs spend an extra hour in the shell gland attributing to an increase in calcium absorption and a concomitant increase in shell weight. Shell weight has been shown to contribute as much as 10 % to total egg weight in a 28 h day length from 30 wk-old broiler breeder hens (Spies et al., 2000). Decreasing the day length back to 24 h can readily reverse the effect of increasing shell weight.

Egg production levels were categorized as Period 1 (47 - 51 wk) and Period 2 (52 - 55 wk) and Entire Period (Table 2-2). Day length had no effect on the rate of egg production in Period 1. However, in Period 2 the ahemeral birds laid significantly fewer eggs than hemeral birds. Previous research has consistently shown that egg production rates reduced as a result of an increase in day length up to 33 h (Morris, 1978; Nordstrom, 1982; Nordstrom and Ousterhout, 1983; Leeson and Summers, 1988; Fitzsimmons and Newcombe, 1991). Shanawany et al. (1993) reported reduced rates of lay more often with birds that had less than six eggs in each sequence as opposed to birds with higher initial rates of lay when subjected to longer day lengths. Rate of lay rarely peaked at six eggs per week for ahemeral birds, which was more characteristic of hemeral birds. The interval between eggs within a sequence extended from 24 - 25 h to 40 - 44 h for old birds on ahemeral schedules in comparison to young birds (Shanawany, 1992). This could be due to reduced follicular maturation rates and does not include pause days. Morris (1978) explained that egg intervals are more affected by the lutenizing hormone (LH) open period rather than follicular maturation rates. The LH open period occurs every 28 h in ahemeral day lengths and can synchronize laying patterns to light cycles between 21 - 30 h. It may be possible that long day lengths decreased follicular sensitivity to pulsatile LH in older broiler breeders.

The incidence of double-yolk eggs was significantly higher during Period 2 in the ahemeral compared to the hemeral group *($P = 0.034$; data not shown)*. This was an unexpected result as previous research has shown that the number of abnormal eggs decreases with longer days (Shanawany, 1982). There were more membranous eggs laid by the hemeral group than the ahemeral group in Period 2 and over the entire period.

Shell Quality

Shell quality was greater in the hemeral group compared to the ahemeral group with specific gravity values of 1.071 and 1.069, respectively (Table 2-3). This result was not expected because previous research has indicated a linear relationship between shell quality and cycle length such that an increase up to 28.5 h increased shell quality (Shanawany, 1990). In three experiments, Rose et al. (1986) consistently demonstrated shell strength improvements using a 28 h day length over a 23 wk period. Several researchers have used another method to examine and measure eggshell quality where shell weight per unit surface area (SWUSA) is expressed as mg/cm^2 (Nordstrom, 1982; Nordstrom and Ousterhout, 1983). In two experiments, SWUSA increased within 1 wk of an ahemeral treatment and also corresponded with increased shell weights. In contrast to previous research, the present study did not show an improvement in shell quality when older breeder hens were managed on an ahemeral light cycle.

Ovarian Characteristics

Absolute values for ovary and oviduct weight were significantly higher for the hemeral group than ahemeral group (Table 2-4). A significant decrease in total follicular weight of all LYF was seen for the ahemeral treatment (49.5 g) compared to the hemeral treatment (55.0 g). Strain FSY had the highest amount of atretic LWF compared to EXP or Classic strains. Egg production for the ahemeral group was lower than hemeral group (Table 2-1). Lower egg production may have been caused by a higher incidence of atresia in LYF in hens in the ahemeral treatment ($P = 0.0702$). Atresia normally occurs because follicles are unable to ovulate due to weak LH surges and low testosterone levels in blood plasma during the open period (Etches, 1984). In addition, it may be normal for older birds to show a higher incidence of atretic SYF and LWF (Palmer and Bahr, 1992). In the present trial, it was found that LYF, SYF and LWF were unaffected by day length or strain with the exception of strain differences in the number of LWF.

Carcass Characteristics

Day length (24 or 28 h) did not significantly affect breast muscle, liver, and fat pad weights. Breast muscle weight differed significantly between the strains, EXP birds displayed the heaviest weight, and Classic birds had the lowest (Table 2-5). This is in agreement with BW data (Table 2-1). Even though the EXP strain had heavier breast muscle weight and BW, these birds produced the lightest eggs on average over the entire production period.

Age Effects

Age effects on the reproductive system of layer hens have previously been studied in birds between 30 to 32 wk of age. Egg production rates tend to decrease with age (Williams and Sharp, 1978). This is because layers in peak egg production have shorter ovulation intervals and require only 24 - 25 h to lay an egg whereas older hens need as long as 40 - 44 h for adequate egg formation (Shanawany, 1992). Williams and Sharp (1978) found young broiler breeder flocks in peak egg production produced an average of 7 LYF compared to 5 per week in 82 wk old flocks. Conversely, even though older hens produced fewer LYF, these follicles were heavier in weight (41.8 g) compared to younger birds (33.6 g). Age also negatively affects the number of potential follicles for ovulation because follicle numbers linearly decrease with age (Robinson et al., 1996) and the number of atretic follicles increases (Palmer and Bahr, 1992). Therefore, older birds generally produce heavier but fewer eggs.

Two factors, molting and long pauses in lay, were unplanned events that negatively affected egg production in the current study. Natural molting in broiler breeder flocks usually occurs between 52 - 60 wk of age (Hazan and Yalcin, 1992) and could result from low protein in the diet (Wilson et al., 1967). Lack of egg production from molting birds contributed to lower average values. Long pauses in lay were noted in egg production records where the hemeral group had three birds with an average of 14 d pauses and the ahemeral group with one bird on a 5 d pause. The fact that hemeral birds had more frequent and longer pauses should have negatively affected egg production. However, even with the presence of these negative factors, hemeral birds still produced more eggs than the ahemeral birds. In this case, it is likely that egg production decreased because a day length of 28 h did not coincide with follicular maturation rates. Increased occurrence of atresia in the ahemeral birds may have also decreased egg production (*P* = 0.0702). Although the incidences of molting and long pauses in lay affected a fraction of the total number of birds in each treatment group, it may have contributed to lower total settable egg production numbers.

Extending the day length from 24 h to 28 h is easily applied to a breeder management program because it amounts to exactly a six-day cycle. Based on the findings from this study, it is not recommended to change the photoschedule at 47 wk of age. Increased egg weights were obtained by an ahemeral treatment but this occurred at the expense of egg production. Overall it was found that smaller ovaries, lower production rates, higher amounts of defective eggs, lower average F1 follicle weights, and poor shell quality resulted from ahemeral day lengths. An increase in egg size late in lay is undesirable in broiler breeder flocks and results in a higher amount of eggs rejected by commercial hatcheries.

TABLE 2-1. Average weekly BW for female broiler breeders from 47 to 55 wk by day length and strain

	Age (wk)								
Source	47	48	49	50	51	52	53	54	55
Day length	BW (kg)								
24 h	3.68	3.71	3.73	3.74	3.74	3.76	3.77	3.77	3.80
28 h	3.74	3.72	3.75	3.76	3.79	3.79	3.82	3.82	3.84
SEM	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Strain[1]									
Classic	3.65^{b}	3.65^{b}	3.66^{b}	3.70	3.68^{b}	3.68^{b}	3.70^{b}	3.71^{b}	3.73^{b}
FSY	3.73^{ab}	3.73^{ab}	3.76^{a}	3.76	3.77^{ab}	3.79^{a}	3.81^{ab}	3.81^{ab}	3.83^{ab}
EXP	3.77^{a}	3.77^{a}	3.80^{a}	3.77	3.83^{a}	3.85^{a}	3.88^{a}	3.87^{a}	3.91^{a}
SEM	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04
	Probability								
Day length	0.0862	0.8388	0.6124	0.6080	0.1974	0.5330	0.2144	0.3559	0.4744
Strain	0.0190	0.0228	0.0126	0.3424	0.0122	0.0093	0.0074	0.0279	0.0141

[a,b]Means within a column with no common superscript differ significantly at $P < 0.05$.

[1] Strain – Classic, FSY (Feather Sexable Yield), or EXP (Experimental).

TABLE 2-2. Day length and strain effects on egg production parameters in broiler breeder females from 47 to 55 wk of age

	Mean egg	Period 1 (47 - 51 wk)			Period 2 (52 - 55 wk)			Entire Period (47 - 55 wk)		
Source	Weight[1]	Total[2]	Settable[3]	Production[4]	Total	Settable	Production	Total	Settable	Production
	(g)	(#)	------------ (%)	--------------	(#)	----------- (%)	-----------	(#)	----------- (%)	-----------
Day length										
24 h	65.58 ^{a}	20.99	98.53	69.96	20.07 ^{a}	98.51	69.21 ^{a}	41.10 ^{a}	98.51	69.67 ^{a}
28 h	67.25 ^{b}	20.02	98.28	66.73	18.86 ^{b}	96.92	65.04 ^{b}	38.97 ^{b}	97.68	66.04 ^{b}
SEM	0 .48	0.40	0.43	1.32	0.42	0.61	1.44	0.75	0.39	1.27
Strain[5]										
Classic	66.92	21.25 ^{a}	98.71	70.83 ^{a}	21.25 ^{a}	98.56	71.24 ^{a}	41.93 ^{a}	98.66	71.07 ^{a}
FSY	66.61	20.53 ^{ab}	98.63	68.44 ^{ab}	20.53 ^{ab}	97.24	67.35 ^{ab}	40.11 ^{ab}	97.94	68.98 ^{ab}
EXP	66.73	19.73 ^{b}	97.87	65.77 ^{b}	19.73 ^{b}	97.35	62.79 ^{b}	38.10 ^{b}	97.68	64.52 ^{b}
SEM	0.59	0.49	0.54	1.65	0.05	0.76	1.78	0.94	0.48	1.59
	----------------------------	----------------------------	----------------------------	----------------------------	------------- P	robability	-------------	----------------------------	----------------------------	----------------------------
Day length	0.0139	0.0860	0.6884	0.0860	0.0413	0.0674	0.0413	0.0462	0.1345	0.0462
Strain	0.5649	0.0936	0.4785	0.0936	0.0042	0.3775	0.0042	0.0151	0.3268	0.0151

[a,b] Means within a column with no common superscript differ significantly at $P < 0.05$.

[1] Mean egg weight : the average weight of all eggs laid per bird.

[2] Total : average of all eggs laid.

[3] Settable : an egg that has a normal, intact shell, and a single yolk.

[4] Production : both normal and defective eggs; calculated as the total number of eggs / number of hens housed and expressed as a percent.

[5] Strain : Classic, FSY (Feather Sexable Yield) or EXP (Experimental).

TABLE 2-3. Egg characteristics for broiler breeder hens at 55 wk of age as affected by day length, strain, age at photostimulation and interactions

	Specific gravity	Fresh weight	Yolk	Albumen	Shell	
		(g)	(g)	(g)	(g)	(% of FW)[1]
Day length						
24 h	1.071^{a}	66.44	20.92	15.6	5.7	8.6
28 h	1.069^{b}	66.75	20.86	15.8	5.6	8.4
SEM	0.0005	0.40	0.16	0.2	0.1	0.1
Strain[2]						
Classic	1.071^{a}	66.40	20.81	15.5	5.8^{a}	8.8^{a}
FSY	1.069^{b}	66.97	21.17	16.1	5.6^{b}	8.3^{bc}
EXP	1.070	66.41	20.68	15.5	5.6^{b}	8.4^{b}
SEM	0.0005	0.52	0.21	0.2	0.1	0.1
Day length X strain						
24 * Classic	1.074^{a}	65.49	20.37^{c}	14.9^{b}	5.9	9.1^{a}
24 * FSY	1.069^{b}	66.79	21.32^{b}	16.2^{a}	5.6	8.4^{b}
24 * EXP	1.069^{b}	67.04	21.16^{bc}	15.7^{a}	5.6	8.3^{b}
28 * Classic	1.070^{cb}	67.32	21.25^{b}	16.1^{a}	5.7	8.5^{b}
28 * FSY	1.068^{b}	67.16	21.04^{abc}	15.9^{a}	5.6	8.3^{b}
28 * EXP	1.070^{bc}	65.78	23.31^{ac}	15.3^{ab}	5.5	8.4^{b}
SEM	0.0008	0.97	0.32	0.4	0.1	0.2
Photo age						
20 wk	1.070	65.97^{b}	20.95	15.7	5.7	8.6
23 wk	1.070	67.22^{a}	20.83	15.7	5.7	8.4
SEM	0.0004	0.40	0.16	0.2	0.1	0.1
Day length X photo						
24 h * 20 wk	1.071	66.19	20.91	15.4	5.7	8.7
24 h * 23 wk	1.071	66.70	20.92	15.7	5.7	8.5
28 h * 20 wk	1.069	65.75	20.99	15.9	5.6	8.5
28 h * 23 wk	1.070	67.76	20.74	15.7	5.7	8.3
SEM	0.0006	0.57	0.23	0.3	0.1	0.1

[a, b, c] Means within a column with no common superscript differ significantly at $P < 0.05$.

[1] % of FW : egg trait weights/fresh weight X 100.

[2] Strain : Classic, FSY (Feather Sexable Yield) or EXP (Experimental).

TABLE 2-4. Day length and strain effects on ovarian characteristics for 55-wk-old female broiler breeders

	Normal ovarian follicles			Atretic ovarian follicles			LYF parameters		Reproductive Organs		
	LYF [1]	SYF [2]	LWF [3]	LYF	SYF	LWF	Total	Average	Oviduct	Ovary [4]	Stroma
	(#)						(g)				
Day Length											
24 h	5.5	7.7	12.7	0.1	3.4	41.2	55.0^{a}	10.1	73.5^{a}	64.5^{a}	9.5
28 h	5.2	7.9	14.4	0.3	4.3	44.1	49.5^{b}	9.5	63.2^{b}	58.8^{b}	9.3
SEM	0.1	0.5	0.7	0.1	0.5	2.6	1.4	0.2	1.4	1.5	0.3
Strain [5]											
Classic	5.4	7.0	12.4	0.1	3.6	42.9^{ab}	50.3	9.3	66.7	59.3	10.0
FSY	5.2	8.1	13.9	0.2	3.9	48.0^{a}	51.7	9.9	70.1	61.3	9.6
EXP	5.5	8.1	14.2	0.4	3.9	37.0^{b}	54.7	10.1	68.2	64.4	9.7
SEM	0.1	0.6	0.8	0.1	0.6	3.2	1.8	0.3	1.7	1.9	0.3
	Probability										
Day Length	0.068	0.77	0.078	0.070	0.16	0.43	0.007	0.081	0.0001	0.008	0.61
Strain	0.47	0.29	0.27	0.29	0.93	0.045	0.18	0.14	0.34	0.14	0.21

[a,b] Means within a column with no common superscript differ significantly at $P < 0.05$.

[1] LYF : large yellow follicles are > 10 mm in diameter.

[2] SYF : small yellow follicles are 5 - 10 mm diameter.

[3] LWF : large white follicles are 3 - 5 mm diameter.

[4] Ovary weight measured when all atretic large yellow follicles removed.

[5] Strain : Classic, FSY (Feather Sexable Yield) or EXP (Experimental).

TABLE 2-5. Day length and strain effects on carcass characteristics for 55-wk-old female broiler breeders

				Breast Muscle Parameters				Abdominal fat pad		Liver	
	Shank Length	Keel Length	Processing BW[1]	*Pectoralis* *Major*	*Pectoralis* *Minor*	Breast[2] Weight	Breast[2] Percent	Weight	Percent	Weight	Percent
	(mm)	(mm)	(kg)	(g)	(g)	(g)	(%)	(g)	(% of BW)	(g)	(% of BW)
Day Length											
24 h	105.3	160.0	3.9	458.9	137.2	596.2	15.5	177.6	4.6	56.8	1.5
28 h	105.7	159.2	3.9	461.6	137.0	598.6	15.3	172.6	4.4	55.8	1.4
SEM	0.5	1.2	0.0	7.1	3.9	8.8	0.2	7.73	0.2	1.1	0.03
Strain[3]											
Classic	104.6	156.4 ^{b}	3.8 ^{b}	425.6 ^{b}	133.6	559.2 ^{c}	14.8 ^{b}	177.2	4.6	54.2	1.4
FSY	106.2	163.1 ^{a}	3.9 ^{a}	457.6 ^{c}	134.9	592.5 ^{b}	15.2 ^{b}	184.0	4.7	56.2	1.4
EXP	105.8	159.4 ^{ab}	4.0 ^{a}	497.6 ^{a}	143.0	640.5 ^{a}	16.2 ^{a}	164.0	4.1	58.5	1.5
SEM	0.6	1.4	0.0	8.8	4.7	10.8	0.2	9.5	0.2	1.4	0.0
	P robability										
Day Length	0.51	0.602	0.16	0.794	0.98	0.842	0.51	0.649	0.40	0.53	0.21
Strain	0.13	0.004	0.012	0.0001	0.32	0.0001	0.001	0.314	0.12	0.080	0.55

[a,b,c] Means within a column with no common superscript differ significantly at $P < 0.05$.

[1] Processing BW : Body weight was measured after bird was killed.

[2] Breast : *Pectoralis major* and *Pectoralis minor* weight combined.

[3] Strain : Classic, FSY (Feather Sexable Yield) and EXP (Experimental).

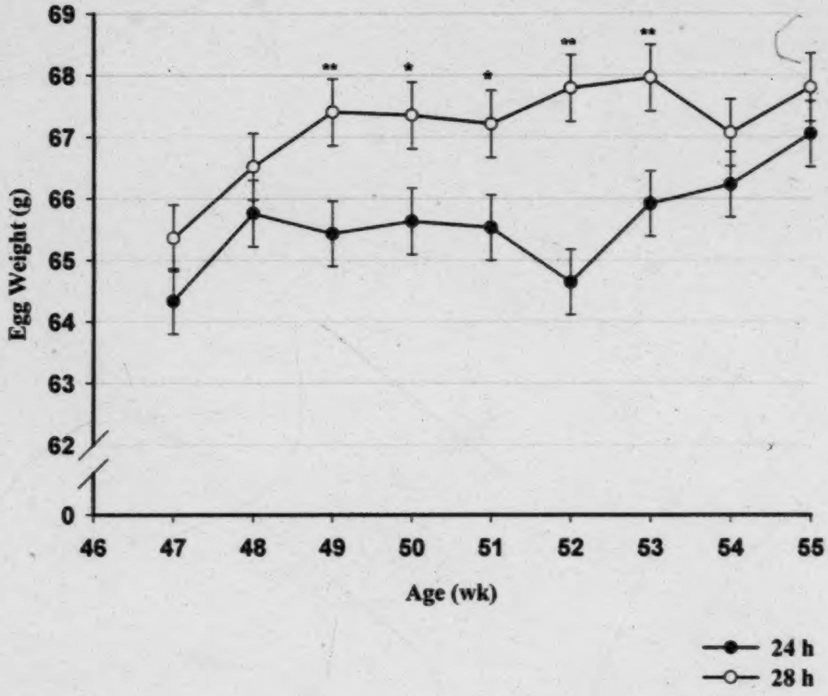

FIGURE 2-1. Effect of day length (24 h vs. 28 h) by age (47 to 55 wk) on egg weight for female broiler breeders. Bars indicate SEM.

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3.0 ADMINISTERING OASIS ® HATCHING SUPPLEMENT PRIOR TO CHICK PLACEMENT INCREASES INITIAL GROWTH WITH NO EFFECT ON BODY WEIGHT UNIFORMITY OF FEMALE BROILER BREEDERS AFTER THREE WEEKS OF AGE

3.1 INTRODUCTION

The time period from hatch to placement can be stressful to the broiler breeder chick due to dehydration and energy depletion. This time interval is comprised of hatching time inside the hatcher, chick processing, chick transportation, and delay of final placement at the farm. Consequently, 48 h can elapse before a newly hatched chick has access to feed and water (Noy and Sklan, 1999a). Previous research has established that a 10 % loss in BW occurred during a 48 h delay in placement (Pinchasov and Noy, 1993). Immediate access to feed and water increased BW until 3 wk of age (Sklan et al., 2000) and up to market age (Vieira and Moran, 1999a) in broilers. Whereas the yolk provides an immediate nutritional source to the chick, delay of feed and water reduced utilization of yolk sac reserves in poults (Moran and Reinhart, 1980). The effect of administrating a chick viability enhancer to compensate for moisture and nutrient losses has been studied. Noy and Sklan (1999a) determined that broiler chicks and turkey poults fed Oasis ® supplement immediately after hatching had improved BW up until market age compared to chicks provided with water or a non-nutrient source such as saw dust.

Pullet BW is maintained by allocating according to target BW growth curves provided by the breeder company. Body weight uniformity can be expressed as both the coefficient of variation (CV) and the percent of birds that are within ± 10 or ± 15 % of the flock mean. A highly uniform flock, or a flock with a high percentage of pullets close to the average target BW, ensures that most birds are receiving optimal nutrient allocation. Flock uniformity is important in broiler breeder pullets because a more uniform flock can translate into a larger percentage of the birds responding optimally to light programs at SM. Akanbi and Goodman (1982) improved BW uniformity in Hisex Leghorns by sorting according to BW at 9 wk of age, but this practice did not significantly affect egg production. In the broiler breeder industry, producers typically attempt to attain 80 % BW uniformity when assessed by using ± 10 % of the flock mean average. Unfortunately, a lower uniformity between 65 to 75 % is often achieved.

The objective of this trial was to examine the effects of holding chicks for 30 h post hatch with or without access to Oasis ® on BW, BW gain and BW uniformity from hatch until 18 wk of age. The hypothesis was that Oasis ® would initially enhance chick BW compared to a control group with a diminishing effect as the rearing period progressed. It was hypothesized that chicks provided with Oasis ® would have improved BW uniformity compared to chicks with no hatching supplement provided.

3.2 MATERIALS AND METHODS

Fertile Egg Handling and Incubation

A total of 2000 Classic [1] line eggs were obtained from a 36-wk old flock. A temperature data recorder was packaged with the eggs during shipping and recorded a transportation temperature range between 22.9 and 25.7 C. All eggs were stored 24 h at 15.1 C and 70 % RH followed by 24 h at room temperature (22.0 C) prior to specific gravity measurements. All eggs were examined for shell integrity and identified. Eggshell quality was assessed by specific gravity. Specific gravity measurements were collected by the flotation method with salt solution concentration increments of 0.02 (concentration range of 1.064 to 1.100). All eggs were stored at room temperature for 15 h after which time they were weighed and placed in a Jamesway incubator [2].

All eggs were candled after 18 d of incubation. Cracked eggs, eggs that were infertile or had dead embryos were removed. After candling, each egg was weighed and placed in an individual hatch basket. Egg moisture loss was calculated as the percent of moisture lost from setting to transfer. All baskets were randomly placed into two Jamesway hatchers [3]. At 21.5 d of incubation, chicks were removed from the hatcher, feather sexed and evaluated for general chick health over a 6 h period. Shell quality, egg set weight and transfer loss weight were determined as background information on the hatch. Male chicks were not required for this study and were killed by cervical dislocation. A total of 856 female chicks were selected for the study. Each chick was leg banded, weighed and placed in plastic chick holding boxes. A total of 107 chicks were randomly placed into each of eight chick boxes so that those hatched in similar baskets and from similar locations in the hatcher were not assigned to the same box. A total of four chick boxes (n = 428) were assigned to one of two treatment groups; chicks receiving Oasis ®[4] (OASIS) and chicks receiving no hatching supplement (CONTROL). This experiment was conducted in accordance with the principles and guidelines set by the Canadian Council on Animal Care (Olfert et al., 1993).

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[1] Aviagen North America, Huntsville, AL, USA, 35805.

[2] Model INC DP 100, Jamesway Incubator Company Ltd., 30 High Ridge Ct., Cambridge, ON, Canada, N1R 7L3.

Oasis ® Treatment and Holding Conditions

The Oasis ® hatching supplement was composed of the following ingredients expressed as a percent of the total weight; soybean meal = 40 - 50 %, grain products (corn) = 15 - 25 %, corn syrup = 10 - 18 %, citric acid = 1 - 5 % and water = 25 - 35 %. After a 6 h processing period, all chicks were subjected to the treatments (OASIS and CONTROL) for 30 h. The 30 h period was used to simulate delays that may occur from hatch to placement. A light schedule was determined in order to match natural day length with transportation procedures; 0 - 6 h hatch processing time (light provided), 6 - 12 h light, 12 - 24 h dark, and 24 - 36 h light. The temperature during the 30 h holding period ranged between 27.0 to 28.3 C (RH not recorded).

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[3] Model HAT DP 100, Jamesway Incubator Company Ltd., 30 High Ridge Ct., Cambridge, ON, Canada, N1R 7L3.

[4] Novus International Incorporated, St. Louis, MO, USA, 63141.

The OASIS group therefore, had access to Oasis ® from 6 to 36 h and the product was evenly distributed in four chick boxes so that each bird was allocated 3.75 g. All chicks were re-weighed after 36 h.

Stocks and Management

Equal numbers of CONTROL and OASIS birds were placed in eight pens (n = 107) according to the treatment groups. Chicks were reared in a light tight facility. The photo period was continuous light {24L (light): 0D (dark)} for the first 3 d followed by 8L : 16D until 18 wk of age. Chicks were fed a starter diet until 4 wk of age (ME = 2880 kcal / kg, CP = 17.8 %) and a grower diet from 4 - 18 wk of age (ME = 2753 kcal / kg, CP = 15.7 %; Table 3-1). All dietary nutrients were fed to meet or exceed National Research Council requirements for breeder pullets (NRC, 1994). After 4 wk the feed was allocated on a daily basis, rather than fed *ad libitum,* in order to meet weekly target BW recommendations (Anonymous, 2000). Body weight for individual birds was recorded at hatch (initial chick weight), 0 wk (hatch + 36 h), 1, 2, 3, 4, 8, 12, 16, and 18 wk of age. Group BW data were recorded during the remaining weeks between 5 and 18 wk for feed allocation determination. Body weight uniformity was calculated using two methods: CV and by the percent of birds per treatment that were within ± 10 or ± 15% of the average. Mortality included dead and culled birds.

Statistical Analysis

The effect of hatching supplement (OASIS and CONTROL) was examined by a one-way ANOVA using the General Linear Models procedure (SAS Institute Inc., 1999). P-values for differences for the LS-means were generated by SAS ® when the main effects were significant (SAS Institute Inc., 1999). Pearson correlation procedure of SAS ® was used to determine relationships between egg and chick weights as well as hatch and post hatch weights and subsequent effects on growth (SAS Institute Inc., 1999). Body weight uniformity, both as a percent and CV, were analyzed by pen (four replications per treatment) in order to examine differences with increasing age (hatch to 18 wk, Steel and Torrie, 1997). Uniformity (CV) data was plotted using SigmaPlot [5] software. Statistical significance was assessed at $P < 0.05$.

3.3 RESULTS AND DISCUSSION

Egg Characteristics and Chick Weights at Hatching and Post Hatch

Shell quality of the eggs was 1.075 as measured by specific gravity. Average egg set weight was 59.64 g with a transfer loss of 12.8 % during incubation and an initial average chick weight of 41.26 g. There was significant difference in chick BW after the 30 h chick holding period. Initially, the OASIS treatment group had lower BW (37.2 g) than the CONTROL (38.0 g). This was not an expected result as opposite results have been previously reported. Noy and Sklan (1999b) provided broiler chicks with immediate access to a commercial starter diet and found that BW increased by 5 g after 48 h whereas BW decreased by 3.5 when chicks were fasted. In another study, Noy and Sklan (1999a) fed Oasis ® hatching supplement to broilers and reported that BW as a percent of control was approximately 126 % after a 34 h holding period and this decreased to approximately 109 % by market age. The control birds in their experiment received no food, water or Oasis ® although the amount of Oasis ® fed to the treatment group was not reported. One hypothesis to explain this result could be that feeding a hatching supplement increased stimulation of the gastro-intestinal tract (GIT) and may have triggered increased amounts of excreta from the gut. Noy and Sklan (1997) suggested that the presence of feed stimulated the amount of yolk that passed from the yolk sac to the GIT. Yolk may have been metabolized at a faster rate in the OASIS birds, increased the amount of contents within the GIT, and could have stimulated increased excreta.

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[5] SigmaPlot for Windows Version 3.03, Jandel Corporation, San Rafael, CA, USA, 94912.

Chick BW decreased in both treatments from the time of hatch to the time of placement 36 h later (Table 3-2). During post hatch holding, the OASIS birds lost 3.9 g and CONTROL birds lost 3.5 g, but this was not significant. Noy and Sklan (1999b) reported a similar weight loss of 3.5 g after control chicks were fasted for 34 h without water, feed or a hatching supplement. Body weight has previously been shown to decrease by 10 % after a 48 h fasting period (Pinchasov and Noy, 1993) and is most likely due to absorption of yolk reserves in the yolk sac as well as weight loss caused from dehydration. The contents of the yolk sac provide the first source of nutrients in the newly hatched chick. Yolk nutrients of mostly fat and protein enable the chick to make the transition from an embryonic life to a neonatal one (Noy and Sklan, 1998).

Post hatch weight loss for the period from hatch to the end of the 30 h holding period (36 h from hatching) was negatively correlated with chick weight at hatching (OASIS = - 60.00 % and CONTROL = - 51.75 %, *P* = 0.0001). This relationship indicates that lighter birds gained weight during the post hatch period whereas heavier chicks may not have consumed as much Oasis ®. In a hatching situation where chick weights are low, a hatching supplement may aid gain in BW, especially in lighter chicks. This could be favorable for hatches with high BW variability.

In this study, it is unknown why the post hatch weights were approximately 2 % lighter in the OASIS compared to the CONTROL broiler breeder chicks. Even though broiler chicks undergo approximately a 48 h period of delay from food and water, small intestines continued to increase in weight by as much as 80 % from initial weight from hatch (Noy and Sklan, 1999b). It was suggested that glucose absorption from yolk sac reserves stimulated intestinal maturation in the hatching chick. In this study, the amount of glucose in Oasis ® was not determined, however, corn syrup was 10 - 18 % of its total weight. The percentage of glucose absorption by the small intestine is moderately high but increases from 43 % near the time of hatching to 90 % by day 4. Yolk passed through the yolk stalk and into the small intestine approximately 1 d before hatching and 5 to 7 d after hatching until reserves have been depleted (Romanoff, 1960). The yolk sac is absorbed without the presence of feed and water but recent literature has stated that yolk sac reserves were utilized at a faster rate in fed compared to fasted broiler chicks (Noy and Sklan, 1996; 1999b). Consumption of feed immediately after hatch may help to stimulate intestinal motility or maturation (Noy and Sklan, 1996; 1999b). The yolk sac in fed birds during the 34 h period after hatch showed a faster exponential utilization, as demonstrated by a decrease in yolk and yolk sac weight, compared to feed-deprived birds (Noy and Sklan, 1999b). Chicks without access to feed show a decrease in gut motility and this may translate into a reduced BW. Noy (1993) showed decreased villi growth after fasting for 48 h and even though normal villi growth resumed 5 to 6 days later, it was still insufficient for fasted birds to catch up in growth as compared to fed birds. Intestinal weight increased but villi development did not occur in fasted birds and this suggests that providing chicks with a hatching supplement during an extended holding period prior to placement may improve intestinal maturation and early BW gains. The results of the present study support this; OASIS birds had significantly higher BW until 4 wk and BW gains until 3 wk of age compared to the birds in the CONTROL group.

Newly hatched chicks require a source of energy because chicks are at risk of developing ketosis, dehydration and energy loss with increasing holding time (Vieira and Moran, 1999b). Ketosis is caused by an excess catabolism of fatty acids from the yolk sac and can be prevented by feeding glucose so that complete dependence upon yolk sac reserves is reduced (Moran, 1989). Other research has stated that energy, especially in the form of glucose is highly available and more significantly absorbed than methionine or oleic acid (Noy and Sklan, 1999b). It is possible that a hatching supplement may prevent ketosis, reduce dehydration, and improve energy for chicks experiencing long delays in placement.

Body Weight During Rearing

Oasis ® had a significant effect on chick BW during the first 4 wk (Table 3-2). The OASIS birds caught up in BW, and exceeded the CONTROL birds by 2.9 g at wk 1, despite a lower BW at wk 0 (Table 3-2). The birds in the OASIS treatment also had greater BW gain from 1 to 3 wk of age (Table 3-2). Vieira and Moran (1999a) found BW gain significantly decreased when broiler chicks were held for 24 h compared to birds that were immediately placed and had access to feed and water; and this effect was most apparent early in life. At wk 4 the reverse effect occurred as CONTROL birds had better BW gains compared to OASIS birds. However, between 16 and 18 wk of age, the OASIS birds had significantly greater BW gains (Table 3-2). In the present study, total BW gain from hatching to 18 wk was not affected by feeding a hatching supplement.

Previous research has shown that fasting for long periods of time can cause permanent, negative effects on BW. Whereas, the current study showed that a 36 h delay did not cause long term negative effects on BW. Body weights at market age in fasted broilers did not catch up to the BW from birds that were given immediate access to feed and water after hatching (Noy and Pinchasov, 1993; Vieira and Moran, 1999a; Sklan et al., 2000). Sklan et al. (2000) fed Cobb broilers directly in hatch trays during the 0 to 22 h period and 22 to 48 h after hatching and found that male and female chicks fed 0 to 22 h had approximately a 5 % BW advantage at 3 wk of age compared to chicks held without feed in either the 0 to 22 h or 22 to 48 h treatment. Body weight gain can be hindered by as much as 10% if chicks are held between 24 to 30 h after hatch (Noy and Pinchasov, 1993). It seems to be crucial for chicks to receive not just water but nutrients from feed or a hatching supplement. Access to water alone does not provide the same improvements in BW compared to allowing chicks immediate access to feed (Noy and Sklan, 1999a). Providing water alone improved broiler chick BW gain until 8 d of age, compared to a BW improvement until 21 d for chicks given feed or feed and water for a 34 h period immediately after hatch (Noy and Sklan, 1999a).

Mortality from hatching to 18 wk remained < 1 % for both treatment groups (CONTROL = 0.9 % and OASIS = 0.7 %). Inclusion of culls from 0 to 18 wk of age increased mortality rates to > 1 %, however, there were no significant differences between the treatments (CONTROL = 5.1 % and OASIS = 8.4 %).

Body Weight Uniformity

Body weight uniformity is expressed as a percent of the flock within either ± 10 or ± 15 % of the mean. Body weight uniformity at ± 10 % was significantly lower for OASIS than CONTROL birds at 1 and 3 weeks of age. Similarly, expressed at ± 15 % of the mean BW, uniformity was also significantly lower for OASIS compared to CONTROL birds at 1 and 2 wk of age (Table 3-3). Body weight uniformity as measured by the CV was more variable in the OASIS group than the CONTROL group at 1 wk of age with no significant effect after this time (Figure 3-1). The results of the BW uniformity data show that during the first 3 wk of life, the OASIS treatment actually had a negative effect on BW uniformity. After 3 wk there was no significant effect of OASIS on BW uniformity compared to the CONTROL. The correlation between post hatch BW loss and hatching chick weights indicated that chicks with a small hatching BW were consuming more of the Oasis product compared to chicks with a heavier hatching BW ($r = 0.60$). However, the uniformity data in this experiment did not show that the chicks in the OASIS treatment had improved uniformity.

These results do not support the hypothesis that improvements in BW uniformity would be achieved from feeding the hatching supplement. Other techniques for improving BW uniformity have been tested. These methods include sorting layer pullets at 9 wk of age (Akanbi and Goodman, 1982), varying the amount of protein in the diet and sorting according to BW

(Petitte et al., 1981) and qualitative feed restriction for broiler breeders (Zuidhof et al., 1995). Although providing Oasis ® may not be an effective way of improving BW uniformity, OASIS supplementation did not negatively affect uniformity after 3 wk. It is not recommended that the Oasis ® product be used to improve uniformity or BW during the brooding period for broiler breeder chicks. Based on the results in this study, a hatching supplement may be helpful in circumventing dehydration of broiler breeder chicks that travel long distances before placement. Future research needs to be conducted to determine if the early BW benefits observed in the present study were due to Oasis ® stimulating intestinal maturation.

TABLE 3-1. Ingredients and nutrient composition of female broiler breeder starter and grower diets

	Starter[1]	Grower[2]
	---------- kg	----------
Diet Ingredients[3]		
Vitamin/mineral premix[4]	5.00	5.00
Wheat shorts	75.00	150.00
Oats	50.00	125.00
Soymeal	173.40	73.70
Corn	141.40	164.40
Wheat	442.30	344.20
Barley	50.00	100.00
Tallow	20.00	0.70
Iodized salt	3.84	3.30
Lysine	0.31	1.62
Methionine	1.41	1.25
Limestone	16.50	17.20
Choline premix	5.00	5.00
Biofos	15.80	8.60
Monensin	0.75	0.50
Nutrient Composition[5]		
Moisture (%)	11.4	11.1
Ash (%)	5.08	4.76
Crude protein (%)	17.8	15.7
Crude fiber (%)	3.4	4.4
Metabolizable energy (kcal / kg)	2880	2753
Crude fat (%)	3.6	3.0
Calcium (%)	0.90	3.48
Phosphorus (%)	0.67	0.83
Potassium (%)	0.77	0.55
Magnesium (%)	0.16	0.16
Sodium (%)	0.15	0.12
Salt (%)	0.37	0.32

[1] Starter diet was fed from 0 to 4 wk of age.

[2] Grower diet was fed from 4 to 18 wk of age.

[3] Diet ingredients: all ingredients were mixed to produce 1000 kg of feed.

[4] Broiler premix provided per kilogram of diet: vitamin A (retinyl acetate), 10,000 IU; cholecalciferol, 2,500 IU; vitamin E (DL-α-tocopheryl acetate), 35 IU; vitamin K, 2.0 mg; pantothenic acid, 14 mg; riboflavin, 5.0 mg; folacin, 0.8 mg; niacin, 65 mg; thiamine, 2.0 mg; pyridoxine, 4.0 mg; vitamin B12, 0.015 mg; biotin, 0.18 mg; iodine, 0.5 mg; Mn, 70 mg; Cu, 8.5 mg; Zn, 80 mg, Se, 0.1 mg; Fe, 100 mg.

[5] All nutrients listed are based on analyzed values.

TABLE 3-2. Average BW and BW gain for broiler breeder pullets from hatching to 18 wk of age

	OASIS [1]	CONTROL [2]	SEM	Probability
BW	---------------- (g)	--------------		
Hatch [3]	41.1	41.5	0.2	0.0530
0 wk [4]	37.2 ^{b}	38.0 ^{a}	0.2	0.0001
1 wk	70.2 ^{a}	67.2 ^{b}	0.4	0.0001
2 wk	113.4 ^{a}	107.6 ^{b}	0.8	0.0001
3 wk	220.1 ^{a}	204.5 ^{b}	2.0	0.0001
4 wk	318.4 ^{a}	306.7 ^{b}	3.0	0.0051
8 wk	792.2	790.7	6.5	0.8697
12 wk	1101.3	1098.6	8.4	0.8177
16 wk	1508.1	1507.8	11.3	0.9861
18 wk	1763.1	1738.1	13.1	0.1719
BW Gain				
Hatch-0 wk	-3.4	-3.5	0.2	0.0841
0-1 wk	33.0 ^{a}	29.2 ^{b}	0.3	0.0001
1-2 wk	43.3 ^{a}	40.4 ^{b}	0.6	0.0002
2-3 wk	106.6 ^{a}	96.8 ^{b}	1.4	0.0001
3-4 wk	98.4 ^{b}	102.1 ^{a}	1.3	0.0390
4-8 wk	473.8	484.1	4.4	0.0934
8-12 wk	309.2	307.9	4.4	0.8438
12-16 wk	406.8	409.2	5.1	0.7335
16-18 wk	255.0 ^{a}	230.3 ^{b}	3.5	0.0001
Total Gain	1725.9	1700.1	13.1	0.1577

$^{a, b}$ Means within a row with no common superscript differ significantly at $P < 0.05$.

[1] OASIS chicks received Oasis ® hatching supplement during holding in chick boxes for 30 h prior to placement.

[2] CONTROL chicks received no hatching supplement during holding in chick boxes for 30 h prior to placement.

[3] Hatch : initial weight of chicks at hatching before treatment.

[4] 0 wk : weight of chicks after treatment imposed for a 30 h holding period.

TABLE 3-3. **Body weight uniformity calculated from hatching to 18 wk of age for female broiler breeders in the OASIS or CONTROL treatments**

	Percent of flock within ± 10% of the average BW				Percent of flock within ± 15% of the average BW			
Variable	OASIS [1]	CONTROL [2]	SEM	P-value	OASIS	CONTROL	SEM	P-value
Hatch [3]	83.51	85.38	2.38	0.5984	95.79	97.23	0.96	0.3328
0 wk [4]	86.38	83.56	3.00	0.5101	96.27	96.15	1.49	0.9572
1 wk	69.62 ^{b}	76.08 ^{a}	1.15	0.0074	84.47 ^{b}	90.34 ^{a}	1.38	0.0237
2 wk	57.13	56.77	2.48	0.9223	72.49 ^{b}	78.13 ^{a}	1.37	0.0272
3 wk	49.94 ^{b}	57.53 ^{a}	2.03	0.0032	61.08	57.53	1.91	0.2360
4 wk	40.49	40.46	2.57	0.9932	61.71	54.94	2.93	0.1539
8 wk	47.59	43.72	3.77	0.4957	63.95	63.30	3.80	0.9065
12 wk	49.70	48.45	4.17	0.8387	69.11	70.86	2.67	0.6602
16 wk	52.08	54.02	3.23	0.6843	57.35	73.86	9.90	0.2828
18 wk	50.92	55.16	2.46	0.2678	70.36	73.57	1.85	0.2661

$^{a, b}$ Means within a column with no common superscript differ significantly at $P < 0.05$.

[1] OASIS chicks received Oasis ® hatching supplement during holding in chick boxes for 30 h prior to placement.

[2] CONTROL chicks received no hatching supplement during holding in chick boxes for 30 h prior to placement.

[3] Hatch : initial hatch weight of chicks before treatment and 36 h holding period.

[4] 0 wk : post hatch weight of chicks after treatment and 36 h holding period.

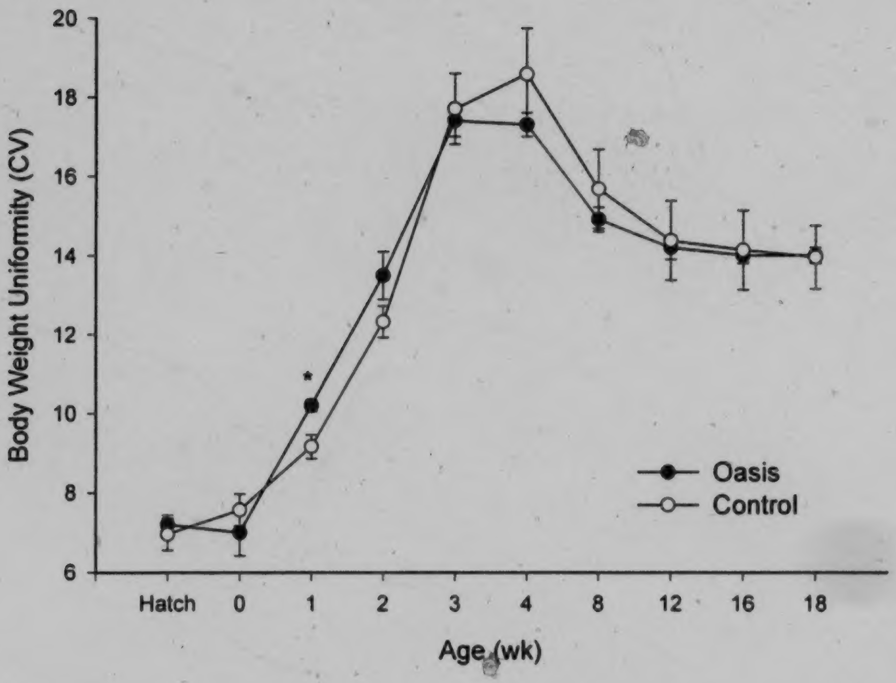

FIGURE 3-1. **Body weight uniformity expressed as CV of BW for broiler breeder pullets in either the OASIS or CONTROL treatment from hatching to 18 wk of age. Significant differences between the two treatments are shown by * ($P < 0.05$). Hatch was defined as the initial weight of all chicks at hatching allocated to each treatment before the treatments were imposed. Week 0 is defined as the weight of chicks per treatment group after the administration of Oasis ® and the 30 h holding period. OASIS birds received Oasis ® hatching supplement before placement whereas CONTROL chicks received no hatching supplement during holding in chick boxes for 30 h prior to placement. Bars indicate the SEM.**

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4.0 FEMALE BROILER BREEDER BREAST MUSCLE MORPHOLOGY AS DETERMINED BY IMAGE ANALYSIS, ULTRASOUND, AND CONFORMATION MEASUREMENTS

4.1 INTRODUCTION

Competition for limited feed may cause variation in breast muscle development in broiler breeder pullets. Aggressive birds may eat more than less aggressive pullets, resulting in differences in fat deposition. Excessive BW and fat pad weights have previously been shown to have a negative consequence on egg production (Robinson and Robinson, 1991; Renema et al., 1999). Breast muscle yield at the commercial level is strongly influenced by genetics and constitutes a major amount of carcass growth in broilers (Halvorson and Jacobson, 1970). Manual determinations of breast muscle fleshing have been used to assess the amount of muscle surrounding the sternum in relation to frame size. This technique determines if birds have adequate breast mass prior to photostimulation, which facilitates reproductive growth (Aviagen North America, Huntsville, Alabama, 35805, Personal Communication).

Data are needed to describe characteristics of breast muscle development as influenced by age and BW. Such characteristics could include breast weight, length, width, and area. Several analytical tools such as computer tomography (Betsen and Sehested, 1989), nuclear magnetic resonance spectroscopy (Mitchell et al., 1991), magnetic resonance imaging (Baulain, 1997), video image analysis (Hahn et al., 1998) and ultrasound (Grashorn, 1996; Konig et al., 1997; 1998) have been previously used. Of all these methods, ultrasonography may have the fewest limitations. It has been used to measure breast muscle thickness and weight in broilers (Grashorn, 1994; Konig et al. 1998) and geese (Cywa-Benko et al., 1999). Anesthesia is not required and real time images allow immediate measurement of breast muscle compared to image analysis (Hahn et al, 1998) or magnetic resonance imaging (Baulain, 1997) of dissected birds. Ultrasonography is widely used in the medical field for monitoring tissue motion and blood flow

(Laugier, 1999). Less is known about the use of ultrasonography as it applies to broiler breeders. Specifically, as it applies to characterizing breast muscle thickness in breeder hens.

The first objective of this study was to characterize the growth of the breast muscle for broiler breeder pullets at three specific ages when feed allocation determination varied relative to three different BW targets. Breast muscle was characterized using several techniques: measuring thoracic width and circumference, calculating a length:width ratio, measuring breast muscle thickness by ultrasound and further characterizing dissected muscles using image analysis. The second objective of this experiment was to determine if the breast muscle thickness measurement from the ultrasound method was consistent with the thickness measurement obtained by image analysis of *Pectoralis major* slice samples. It was expected that breast muscle thickness measurements obtained by ultrasound would provide a reliable assessment of muscle deposition in breeders.

4.2 MATERIALS AND METHODS

Stocks and Management

Classic [1] broiler breeders were reared in a light-tight facility and received continuous light (24L : 0D) for the first 3 d followed by 8D : 16L until 22 wk of age. Pullets were fed as follows: starter diet until 4 wk of age (ME = 2880 kcal / kg, CP = 17.8 %); grower diet from 4 to 22 wk of age (ME = 2753 kcal / kg, CP = 15.6 %); breeder layer diet from 22 to 26 wk of age (ME = 2280 kcal / kg, CP = 19.4 %). Pullets were fed *ad libitum* until 3 wk of age at which time feed restriction was imposed. All dietary nutrients were fed to meet or exceed NRC requirements for breeder pullets (NRC, 1994). At 18 wk of age, 108 pullets were selected based on the BW they had achieved during the rearing period and assigned to one of the following BW groups: Standard (STD) were at target BW as suggested by the Arbor Acres Broiler Breeder Management

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[1] Aviagen North America, Huntsville, AL, USA, 35805.

Guide (Anonymous, 2000); Low (LOW) birds were 15 % lighter than STD birds; High (HIGH) birds were 15 % heavier than STD birds; n = 36 / group. Following individual caging, feed allocation of LOW and HIGH birds were adjusted to maintain a similar rate of gain to the STD birds on the target BW growth curve. Body weight differences (above or below 15 %) were accomplished by feeding 7 % more or less feed, respectively. Birds were photostimulated at 22 wk with a photoperiod of 15L : 9D. Birds within each BW group (LOW, STD, and HIGH) were randomly assigned to one of three processing ages (18, 22, or 26 wk of age; n = 12 / per BW group). Breast muscle conformation (thickness, area, width, and weight) and fat pad weight was recorded at processing. This experiment was conducted in accordance with the principles and guidelines set by the Canadian Council on Animal Care (Olfert et al., 1993).

Techniques Used to Measure Breast Muscle

Body weight was recorded on a weekly basis. Weekly breast conformation measurements included thoracic circumference, thoracic width, and keel length. Thoracic circumference was measured using a flexible measuring tape placed around the girth in alignment with the cranial end of the sternum, approximately 2.5 cm below the clavicle bone. Thoracic width was measured with a 30-cm caliper, placed perpendicular to the cranial end of the sternum, which was visually the widest part of the breast. Keel length was measured with a 20-cm caliper from the lower point of the clavicle joint to the caudal end of the sternum. A thoracic length:width ratio was calculated from keel length (mm) and thoracic width (mm) conformation measurements.

Breast muscle thickness was measured using real time ultrasound [2] procedures on live birds at each processing age. Each bird was externally marked using a permanent black marker at four points of measurement on the breast prior to dissection (Figure 4-1). Two points were marked on the upper sections of the breast, above the coracoid and near the top of the shoulder with one on the left and one on the right. Two points were marked on the lower sections of the breast, approximately 2.5 cm parallel to the top of the sternum with one on the left and one on the right. Placement of the upper and lower ultrasound points corresponded with the positions of the upper and lower ultrasonic measurements surveyed on live birds (Figure 4-1). Ultrasonic gel was applied to a 5 MHz transducer to facilitate contact between bird skin and transducer. The transducer provided an adequate reading when it was placed on the skin without removing the feathers. Birds were held still on their backs and the transducer was positioned in an upright, vertical position to the breast muscle, and two-dimensional images were recorded.

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[2] Model SSD-500, Aloka Ulatrasound Diagnostic Equipment, Aloka Co. Ltd., Tokyo, Japan, 181-8622.

Each bird was killed by cervical dislocation after the ultrasound procedure. Breast muscle (*Pectoralis major* and *minor)* and fat pad were removed and weighed. The *Pectoralis major* was digitally photographed using image analysis software [3] as a technique to describe linear measurements (length, width and area) of the dissected breast muscle. The following measurements were taken from the whole breast digital image: length (line 1 and line 2); center length (line 3), half line (line 4) and widest line (line 5; Figure 4-2).

Long and wide slice samples were cut from the whole breast muscle using a 1-cm wide double-blade scalpel. A long slice (Figure 4-3A) was obtained from the anatomical left half of the breast muscle by slicing from the top of the shoulder to the posterior end of the sternum following line 1 from the whole breast (Figure 4-2). A wide slice (Figure 4-3B) was obtained from the anatomical right half of the breast muscle following line 5 (Figure 4-2). Both long and wide slices were measured for length, width and area (Figure 4-3). The following measurements were taken from the long slice: upper thickness (line 1); middle thickness (line 2); lower thickness (line 3); length (line 4; Figure 4-3A). The following measurements were taken from the wide slice: outer (line 5); middle (line 6); inner (line 7); length (line 8; Figure 4-3B). Both long and wide slices were cut from each breast in order to compare ultrasound results with image analysis. Upper ultrasound points were positioned with the intent of correlating them with the outer thickness of the dissected long slice from the whole breast muscle. Lower ultrasound points were positioned with the intent of correlating them with the Inner thickness of the dissected wide slice from the whole breast muscle.

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[3] Northern Exposure, Empix Imaging Inc., Mississauga, ON, Canada, L5L 5M6.

Statistical Analysis

A 3 X 3 factorial design was used to examine the main effects of BW group (LOW, STD, and HIGH) and processing age (18, 22, and 26 wk of age). All main treatment effects and interactions were tested for significance at $P < 0.05$ using the General Linear Models procedure (SAS Institute Inc., 1999). P-values for differences for the LS-means were generated by SAS ® when the main effects or interactions were significant (SAS Institute Inc., 1999). Pearson correlation coefficients of SAS ® were generated to compare all techniques for measuring breast conformation (SAS Institute Inc., 1999). Ultrasound upper (left and right) and lower (left and right) measurements were averaged to obtain one measurement for upper breast and one for lower breast. Whole breast length (line 1 and line 2) measurements obtained from image analysis were also averaged to a single value per bird.

4.3 RESULTS AND DISCUSSION

Live Bird Morphology

Thoracic circumference, thoracic width, keel length increased with age and BW (Table 4-1). The length:width ratio, used to describe the amount of breast muscle growth in relation to the length of the sternum, decreased as birds aged (18 wk = 2.31, 22 wk = 2.18, and 26 wk = 1.97) and decreased with increasing BW (LOW = 2.18, STD = 2.17, and HIGH = 2.10). A higher ratio represented less flesh coverage on the sternum. The ratio decreased with age because breast muscle grew to a greater extent than the sternum.

The birds were photostimulated at 22 wk of age to promote reproductive maturity. It has previously been suggested that muscle growth decreases after photostimulation because birds allocate food resources to reproduction rather than muscular growth (Joseph, 2000). However, in the current experiment, the 26-wk old birds continued to exhibit significant growth after photostimulation. Breast muscle increased by 32.1 % from 18 to 22 wk and a further 15.8 % from 22 to 26 wk of age. Sexual maturation was expected to occur between 25 to 26 wk of age and consequently, the 26 wk processing age group had some birds that were reproductively mature (data not shown). It was clear that these breeders allocated feed resources to both breast muscle and reproductive growth in response to photostimulation.

Carcass Characteristics at Processing

Breast muscle weight increased with increasing BW (Table 4-1). Similarly, birds that had heavier breast muscle also had heavier fat pads compared to their lighter counterparts. Fat pad weight increased by 78.9 % compared to breast muscle weight, which increased by half as much as the fat pad (42.8 %) from 18 to 26 wk of age. Renema et al. (1999) previously showed that abdominal fat pad highly correlated with carcass lipid weight. The time between 18 to 26 wk of age is a critical growth period in the broiler breeder because the reproductive organs begin to develop during this time. A high level of fatness was present in these birds which is expected to occur as they approach SM (Robinson et al., 1996). However, breast muscle growth was also rapid during this critical period.

Breast Muscle Morphology Characterized by Image Analysis

Digitally photographing each dissected breast muscle was useful in determining linear measurements of the breast muscle relative to age and BW (Table 4-2). The area of the

Pectoralis major was similar between 18 wk and 22 wk but smaller than the 26 wk birds (18 wk = 214.6 cm^2 22 wk = 217.8 cm^2, and 26 wk = 245.6 cm^2). Similarly, the average length, center length and half line of the whole breast was similar for 18 and 22 wk birds and these measurements of the whole breast were shorter than at 26 wk of age. However, the widest line measurement of the whole breast increased with time (18 wk = 17.3 cm, 22 wk = 17.8 cm, and 26 wk = 18.9 cm). It was expected that these measurements would continue to increase in time. However, apart from the widest line, all other measurements at 18 and 22 wk of age were similar.

The dissected breast muscle measurements of area and length increased as BW increased (Table 4-2). Measurements of center length, half line and the widest line were similar between STD and HIGH birds but longer and wider than the measurements obtained from LOW birds. An interaction for the half line showed that LOW birds had smaller breast muscle width compared to STD and HIGH birds at 18 wk of age, but was similar at 22 and 26 wk of age. The LOW birds may still be developing breast muscle in the width at 18 wk of age, whereas this was not the case in STD or HIGH birds ($P = 0.005$; data not shown). In the same interaction, the half line from breast muscle in HIGH birds did not show differences with age in time, which suggests that breast muscle width for larger framed, heavier birds does not increase after 18 wk of age. These birds (HIGH) reached their mature conformation at a younger age than LOW birds. The widest part of the breast continued to grow with advancing age in LOW birds. However, for STD and HIGH birds the widest line remained the same for 18 and 22 wk, followed by a significant increase by 26 wk of age. Overall, it was evident that LOW birds did not grow as quickly as STD and HIGH birds. Slower breast muscle growth in the LOW birds was most likely associated with a lack of sufficient feed that can occur as a result of feed restriction. The LOW birds were seemingly unable to meet their maximum growth potential.

Breast Muscle Morphology Characterized by Ultrasound

The thickness of the breast muscle increased with age for upper and lower breast values (Table 4-1). Feed allocation had less of an effect on the breast muscle thickness as both STD and HIGH birds had similar measurements. However, LOW birds had significantly lower breast muscle measurements than their heavier counterparts. Interaction between processing age and BW group showed that pullets in the LOW BW group lagged behind in their ultrasound and image analysis measurements within all processing age (18, 22, and 26 wk). The interaction at the half line measurement, as obtained by image analysis, demonstrated that birds with HIGH BW had similar breast width at all processing ages (18 wk = 17.7mm, 22 wk = 17.7 mm, and 26 wk = 18.6 mm, $P = 0.0051$). At 26 wk of age, breast thickness of the upper breast was similar between STD (26.5 mm) and HIGH birds (26.3 mm), but not compared to LOW birds (25.0 mm; $P = 0.048$). These results demonstrated that birds with LOW BW were lagging behind birds with a STD or HIGH BW, even within each processing age. Low levels of CP in the diet have been shown to reduce muscle development (Acar et al., 1993). However, suppressed growth in the LOW birds was most likely due to a lack of feed as CP level was the same in all treatments. Birds with low BW in a flock may develop more breast muscle before photostimulation if more feed is available.

The upper and lower ultrasound points correlated, indicating that one point, rather than four, may be adequate to obtain meaningful results (Table 4-3). Ultrasound measurements highly correlated with breast muscle weight (Table 4-3), which supports previous results. Konig et al. (1998) found ultrasound measurement to be the best predictor of breast muscle weight, rather than live weight in broiler chickens. A high correlation coefficient was also found between breast muscle thickness measurements obtained by dissection and by experiments using ultrasound in turkeys (Rose, 1986); ducks (Sörensen and Jensen, 1992) and broiler (Grashorn and Komender, 1990; Grashorn, 1994). Both ultrasonography and the caliper were useful tools for measuring thoracic width. The upper ultrasound thickness measurement correlated well with the thoracic width conformation measurement compared to all other conformation measurements (Table 4-3). It is more economical and less labor intensive to use the caliper compared to the ultrasound, as the caliper maybe a sufficient for measuring breast muscle thickness near the top of the breasts.

One of the objectives in this experiment was to determine if the breast muscle thickness measurement from the ultrasound method was consistent with the thickness measurement obtained from image analysis when long and wide slices were taken from the *Pectoralis major*. The correlation coefficients between upper and lower ultrasound points with slice measurements was not consistent (Table 4-4). The thickest measurement of the long slice (line 1, Figure 4-3A) presumably related to average of upper ultrasound points, was only found to be significantly correlated with the upper ultrasound points at 22 wk of age. The inner thickness of the wide slice (line 6, Figure 4-3B) intended to relate to the lower ultrasound points, correlated significantly with the lower ultrasound points at 22 and 26 wk of age. Lower ultrasound points showed correlation with center length at 18 ($r = 0.39$) and 22 wk ($r = 0.42$) of age which could suggest that breast muscle thickness increased as keel length increased.

Although measurements of thickness by ultrasound and thickness by image analysis were not strongly related to one other, these results do not suggest that the ultrasound or image analysis are inaccurate tools for characterizing the breast muscle in broiler breeder females. Cywa-Benko et al. (1999) previously demonstrated that the ultrasound method was a useful tool for accurately measuring breast muscle thickness in geese, whereby the most accurate site was 2.5 cm from the top of the sternum. A digital photograph of each dissected breast muscle was a useful technique for describing measurements such as length, width and area. However, application of the image analysis method may be more limited by human error than the ultrasound method. In this study, several different technicians removed slices from the whole breasts rather than one individual. One individual performing these slices may have increased the accuracy of the measurements from the image analysis and could account for the lack of significance across all the processing ages. The ultrasound procedure was performed by an experienced individual, which could have contributed to more reliable results in the breast muscle thickness measurements.

This study showed that breast muscle thickness was more affected by age than by BW. Smaller birds required a longer period of time to develop breast muscle compared to larger birds. Breast muscle growth was evident after photostimulation at 22 wk of age when bird resources were most likely allocated to muscular and reproductive growth. Image analysis measurements and ultrasound measurements did not show consistent correlation with each another indicating that both techniques describe different characteristics of the breast muscle growth. Ultrasound may be a better tool for characterizing the breast muscle because it can be applied to live birds whereas the image analysis technique is limited to measurements pertaining to dissected breast muscles. Further study is necessary to determine the age at which muscular growth is attained and how reproductive function is affected when growth is not attained before sexual maturity.

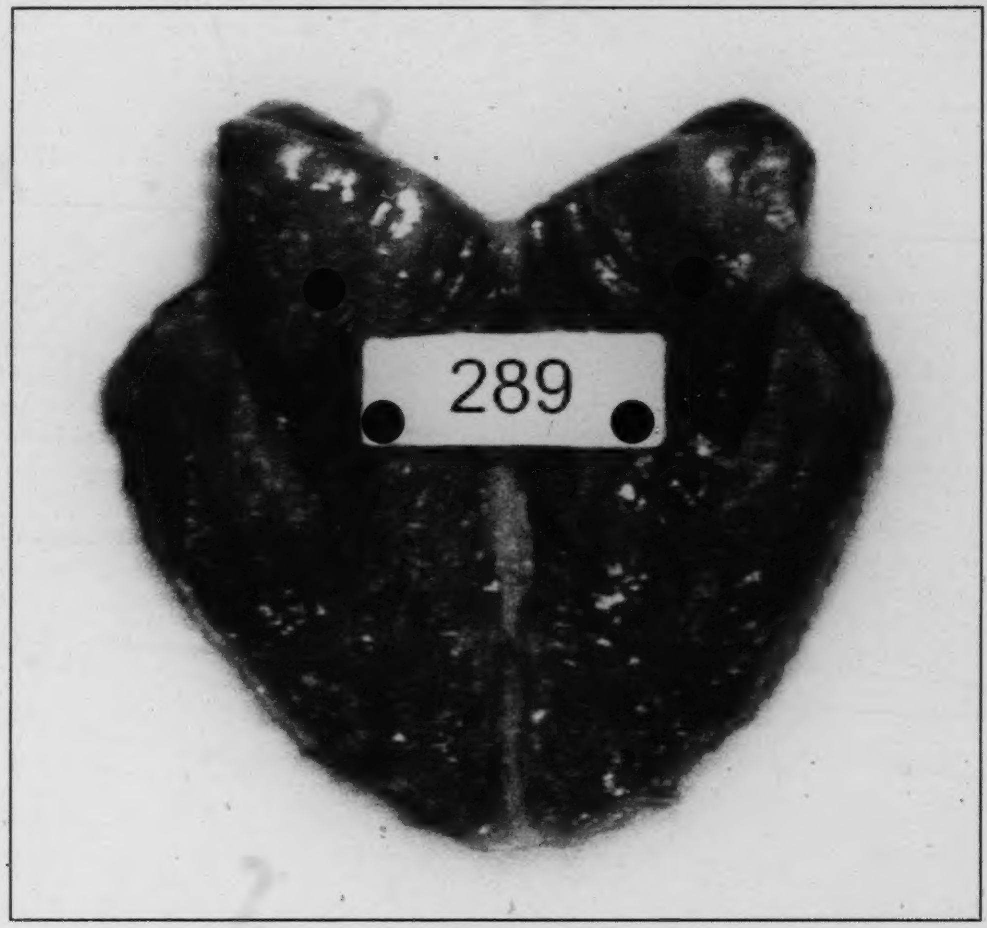

FIGURE 4-1. Digital image of a *Pectoralis major* dissected from a female broiler breeder. Placement of the upper and lower black marks indicated the relative position of upper and lower ultrasonic measurements surveyed on live birds.

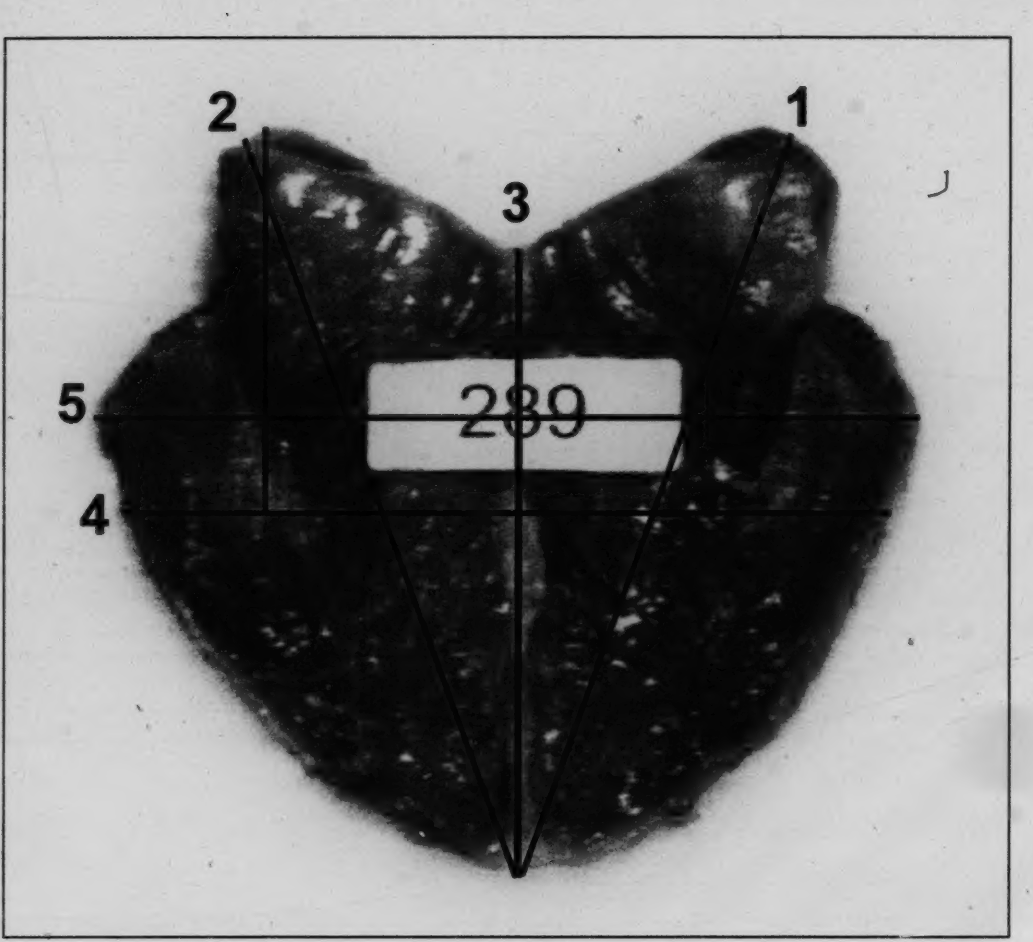

FIGURE 4-2. Digital image of a *Pectoralis major* dissected from a female broiler breeder. The following measurements were determined for each breast muscle image. 1: right length, 2: left length, 3: keel length, 4: half line (line perpendicular to keel at the midpoint of the breast), 5: widest line (taken at the widest point across the muscle).

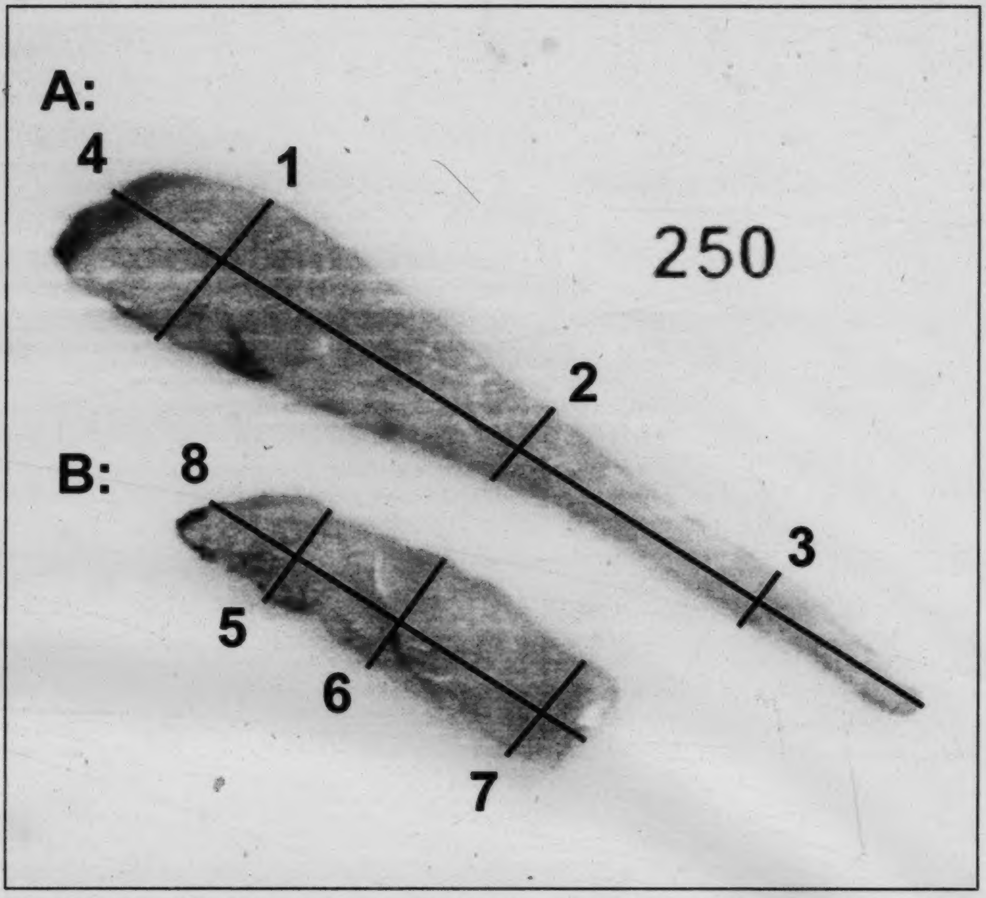

FIGURE 4-3. Digital image of long and wide slices from the *Pectoralis major* of a female broiler breeder. A: The long slice was removed using a double bladed scalpel taking a 1-cm wide transverse section from the left side of the muscle beginning at the top of the shoulder and continuing downwards to the keel. Linear measurements were made on the long slice, 1: upper thickness, 2: middle thickness, 3: lower thickness, 4: length. B: The wide slice shown is a 1-cm thick transverse section taken from the right side of the *Pectoralis major* beginning at the keel attachment and continuing right to the edge of the muscle. The wide slice followed half of the widest line measure on the whole *Pectoralis major* muscle. Linear measurements on the wide slice were 5: outer thickness (refers to furthest position from the keel), 6: middle thickness, 7: inner thickness, 8: length. Line 7 from the wide slice was closest to the keel.

TABLE 4-1. Breast conformation and carcass characteristics for female broiler breeders in processing age and BW groups

Variable	Processing age			BW group[1]			
	18 wk	22 wk	26 wk	LOW	STD	HIGH	SEM
	----------- n = 12 / age -----------			-------- n = 36 / BW group -------			
BW (g)	1,808.3 ^{c}	2,378.3 ^{b}	2,900.8 ^{a}	2,090.6 ^{c}	2,382.0 ^{b}	2,614.9 ^{a}	22.0
Thoracic circumference (mm)	312.6 ^{c}	329.9 ^{b}	345.7 ^{a}	317.8 ^{c}	332.1 ^{b}	341.4 ^{a}	1.5
Keel length (mm)	140.7 ^{c}	147.7 ^{b}	155.7 ^{a}	144.0 ^{c}	148.5 ^{b}	151.5 ^{a}	0.7
Thoracic width [2] (mm)	61.3 ^{c}	68.0 ^{b}	79.1 ^{a}	66.7 ^{c}	69.1 ^{b}	72.6 ^{a}	0.6
Length:width ratio [3]	2.31 ^{a}	2.18 ^{b}	1.97 ^{c}	2.18 ^{a}	2.17 ^{a}	2.10 ^{b}	0.02
Upper ultrasound [4] (mm)	18.3 ^{c}	22.8 ^{b}	26.0 ^{a}	20.5 ^{b}	23.0 ^{a}	23.5 ^{a}	0.3
Lower ultrasound [5] (mm)	17.6 ^{c}	23.3 ^{b}	26.0 ^{a}	20.7 ^{b}	22.8 ^{a}	23.4 ^{a}	0.3
Breast muscle [6] (g)	278.4 ^{c}	410.0 ^{b}	487.0 ^{a}	345.3 ^{c}	398.3 ^{b}	431.8 ^{a}	5.6
Breast muscle [7] (%)	15.3 ^{c}	17.2 ^{a}	16.6 ^{b}	16.2	16.6	16.5	0.2
P. Major (g)	207.0 ^{c}	308.1 ^{b}	364.1 ^{a}	259.8 ^{c}	297.2 ^{b}	322.2 ^{a}	4.4
P. Major (%)	11.4 ^{c}	13.0 ^{a}	12.4 ^{b}	12.2	12.4	12.3	0.1
P. Minor (g)	71.3 ^{c}	102.0 ^{b}	122.9 ^{a}	85.5 ^{c}	101.1 ^{b}	109.6 ^{a}	1.7
P. Minor (%)	3.9 ^{b}	4.3 ^{a}	4.2 ^{a}	4.0 ^{b}	4.2 ^{a}	4.2 ^{ab}	0.1
Fat pad (g)	18.5 ^{c}	39.3 ^{b}	87.7 ^{a}	30.4 ^{c}	48.4 ^{b}	66.6 ^{a}	2.9
Fat pad (%)	1.0 ^{c}	1.6 ^{b}	3.0 ^{a}	1.3 ^{c}	1.9 ^{b}	2.4 ^{a}	0.1

$^{a\text{-}c}$ Means within a row and within a treatment with no common superscript differ significantly at $P < 0.05$.

[1] BW group: STD = target BW level according to Arbor Acres Broiler Breeder management guide;

LOW = BW 15 % below STD; HIGH = BW 15 % above STD.

[2] Measurement taken across the breast of the bird above the top of the sternum.

[3] Calculated ratio of keel length to thoracic width.

[4] Average of left and right ultrasound measurements on upper part of the breast muscle.

[5] Average of left and right ultrasound measurements on lower part of the breast muscle.

[6] Breast weight includes both *P. Major* and *P. Minor*.

[7] Breast muscle : % of BW.

TABLE 4-2. Morphology of the *Pectoralis major*, using digital image analysis,[1] for female broiler breeders in processing age and BW groups

	Processing age			BW group [2]			
Variable	18 wk	22 wk	26 wk	LOW	STD	HIGH	SEM
	----------- n = 12 / age --------			------ n = 36 / BW group -----			
Whole breast measures [3]							
Area (cm^2)	214.6^{b}	217.8^{b}	245.6^{a}	206.9^{c}	230.3^{b}	240.8^{a}	2.8
Length [4] (cm)	18.0^{b}	17.8^{b}	19.3^{a}	17.9^{c}	18.4^{b}	18.8^{a}	0.2
Center length (cm)	14.1^{b}	14.0^{b}	15.3^{a}	14.0^{b}	14.5^{a}	14.8^{a}	0.1
Half line (cm)	16.7^{b}	17.2^{b}	18.1^{a}	16.3^{b}	17.7^{a}	18.0^{a}	0.2
Widest line (cm)	17.3^{c}	17.8^{b}	18.9^{a}	17.0^{b}	18.4^{a}	18.5^{a}	0.2
Long slice measures [5]							
Length (cm)	21.5^{b}	21.2^{c}	22.6^{a}	21.2^{b}	22.0^{a}	22.1^{a}	0.2
Upper [7] (cm)	2.3^{b}	3.5^{a}	3.4^{a}	2.9^{b}	3.1^{ab}	3.2^{a}	0.1
Middle (cm)	1.33^{c}	1.75^{b}	1.88^{a}	1.57^{b}	1.69^{ab}	1.70^{a}	0.04
Lower (cm)	0.78^{c}	1.11^{b}	1.22^{a}	1.99	1.05	1.07	0.03
Wide slice measures [6]							
Area (cm^2)	15.0^{c}	20.4^{b}	23.8^{a}	18.0^{b}	19.9^{a}	21.2^{a}	0.5
Length (cm)	10.8^{c}	10.3^{b}	11.9^{a}	10.5^{a}	11.2^{b}	11.4^{a}	0.2
Outer (cm)	1.6^{b}	2.2^{a}	2.1^{a}	1.9^{b}	2.0^{ab}	2.1^{a}	0.1
Middle (cm)	1.2^{b}	2.3^{a}	2.2^{a}	1.8^{b}	1.9^{ab}	2.0^{a}	0.1
Inner [8] (cm)	1.6^{b}	2.2^{a}	2.3^{a}	2.0^{b}	2.0^{ab}	2.1^{a}	0.1

$^{a-c}$Means within a row with no common superscript differ significantly at $P < 0.05$.

[1] Digital image analysis - using the software program Northern Exposure® by Empix Imaging Inc., Mississauga, ON, Canada, L5L 5M6.

[2] BW group : STD = target BW level according to Arbor Acres breeder guide; LOW = BW 15% below STD; HIGH = BW 15% above STD.

[3] Whole Breast measures : length = average of longest lines from tip of shoulder to bottom of the keel; widest = line perpendicular to keel at widest point of the breast; half = line perpendicular to the keel at the midpoint of the breast.

[4] Average length of line 1 and 2 from the whole breast. Each line begins at the top of the shoulder and continues downwards to the keel.

[5] Long slice : 1-cm wide slice following line 1 of the whole breast. Transverse section of *P. Major* taken from the left side of the muscle beginning at the top of the shoulder and continuing downwards to the keel.

[6] Wide slice : 1-cm wide slice following the widest line. Transverse section of the *P. Major* taken from the right beginning at the sternum and continuing to the end of the muscle.

[7] Upper : uppermost thickness near the top of the breast.

[8] Inner : innermost thickness towards the keel.

TABLE 4-3. Correlation coefficients used to describe the relationship between conformation measurements and ultrasound measurements of female broiler breeders

	Upper Ultrasound [1]			Lower Ultrasound [2]		
Variable	18 wk	22 wk	26 wk	18 wk	22 wk	26 wk
Upper breast	.	.	.	0.76 [3]	0.69	0.76
	.	.	.	0.0001 [4]	0.0001	0.0001
Breast weight	0.74	0.79	0.73	0.77	0.80	0.79
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Breast width	0.41	0.57	0.56	0.23	0.71	0.45
	0.0153	0.0003	0.0004	0.1943	0.0001	0.0057
Thoracic circumference	0.56	0.67	0.31	0.49	0.65	0.31
	0.0022	0.0001	0.0620	0.0030	0.0001	0.0666
Keel length	0.57	0.43	0.27	0.47	0.54	0.27
	0.0005	0.0083	0.1053	0.0055	0.0008	0.1103
Length:width ratio	-0.12	-0.36	-0.36	- 0.97	-0.45	-0.26
	0.4907	0.0302	0.0293	0.008	0.0055	0.1253

[1] Average of left and right ultrasound measurements on the upper part of the breast muscle.

[2] Average of left and right ultrasound measurements on the lower part of the breast muscle.

[3] Correlation coefficient.

[4] Probability is indicated immediately below the correlation coefficient.

TABLE 4-4. Correlation coefficients used to describe the relationship between digital image analysis[1] of slices from the *P. Major* and ultrasound measurements of female broiler breeders

	Upper Ultrasound [2]			Lower Ultrasound [3]		
Parameter	18 wk	22 wk	26 wk	18 wk	22wk	26 wk
Area *P. major*	0.64 [4] 0.0001 [5]	0.40 0.0157	0.29 0.0835	0.69 0.0001	0.57 0.0003	0.29 0.0878
Average Length [6]	0.33 0.0542	0.26 0.1216	0.32 0.0550	0.30 0.0870	0.49 0.0023	0.27 0.1163
Center length	0.34 0.0480	0.23 0.1826	0.18 0.2849	0.39 0.0218	0.42 0.0115	0.16 0.3493
Half width[7]	0.56 0.0006	0.26 0.1212	0.11 0.5311	0.69 0.0001	0.41 0.0133	0.19 0.2696
Widest [8]	0.56 0.0007	0.27 0.1162	0.08 0.6368	0.73 0.0001	0.43 0.0082	0.59 0.0940
Long slice [9] thickest [10]	0.21 0.2439	0.47 0.0042	0.29 0.0877	0.11 0.5292	0.23 0.1794	0.29 0.0810
Long slice middle	0.11 0.5527	0.3435 0.0402	0.11 0.5187	0.04 0.8306	0.07 0.6843	0.20 0.2449
Long slice thinnest	0.14 0.4267	0.39 0.0197	0.05 0.7550	0.10 0.5908	0.16 0.3621	0.14 0.4008
Long slice length	0.37 0.0325	0.36 0.8334	0.42 0.0109	0.43 0.0094	0.28 0.0978	0.28 0.0990
Wide slice outer [11]	0.16 0.3684	0.26 0.1245	0.37 0.0452	-0.22 0.2091	0.11 0.5154	0.44 0.0068
Wide slice middle	0.11 0.5329	0.30 0.0711	0.44 0.0067	0.94 0.0127	0.24 0.1628	0.35 0.0369
Wide slice inner [12]	0.05 0.7973	0.59 0.0001	0.27 0.1095	-0.18 0.3140	0.46 0.0045	0.35 0.0360
Wide slice length	0.60 0.0002	0.7732 0.05	0.94 0.01	0.70 0.0001	0.60 0.0906	0.88 0.0270
Wide slice area	0.46 0.0058	0.61 0.0001	0.31 0.0643	0.45 0.0074	0.45 0.0060	0.34 0.0413

[1] Digital image analysis: software program Northern Exposure ® (Empix Imaging Inc., Mississauga, ON, Canada, L5L 5M6).

[2] Average of ultrasound measurements on upper part of the breast muscle.

[3] Average of ultrasound measurements on lower part of the breast muscle.

[4] Correlation coefficient.

[5] Probability is indicated immediately below the correlation coefficient.

[6] Average length of line 1 and 2 from the whole breast. Each line begins at the top of the shoulder and continues downwards to the keel.

[7] Half : line perpendicular to keel at the midpoint of the breast.

[8] Widest : line perpendicular to keel at widest point of the breast.

[9] Long slice : 1 cm wide slice following line 1 of the whole breast. Transverse section of *P. Major* taken from the left side of the muscle beginning at the top of the shoulder and continuing downwards to the keel.

[10] Thickest : upper part of the breast, nearest the shoulder and wing attachment.

[11] Wide slice : 1 cm wide slice following widest line. Transverse section of the *P. Major* taken from the right beginning at the keel and continuing to the end of the muscle.

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5.0 SEXUAL MATURATION OF BROILER BREEDER PULLETS VARYING IN BODY WEIGHT

5.1 INTRODUCTION

Pullets reach sexual maturity (SM) as soon as the ovary is competent for egg production. Research has shown that threshold BW affected the timing of SM in pullets from dwarf or non-dwarf populations (Brody et al., 1984) and in White Rock breeders (Soller et al., 1984). Dunnington and Siegel (1984) proposed that a combination of chronological age and minimum BW were necessary before SM occurred in White Leghorns. Others, using Hubbard broiler breeder hens, suggested the onset to SM was affected by a threshold degree of body fatness (Bornstein et al., 1984). Time of SM may also be influenced by genetic variability. Egg layers that were classified as being either early maturing (ISA Babcock B300) or late maturing (Shaver White) showed evidence of variation in reproductive maturation rate (Robinson et al., 2001).

Endocrine signals originating from the hypothalamus are important for initiating follicular development and sexual maturation in meat-type hens. The competency for a follicle to mature and ovulate depends not on size and weight but on its ability to produce progesterone (Etches et al., 1983). The production of progesterone occurs in response to a surge of luteinizing hormone (LH) (Etches, 1996b). The hypothalamus produces gonadotrophin-releasing hormone (GnRH) which causes the release of gonadotrophins such as LH, and the production of hormones such as progesterone and estradiol. Luteinizing hormone and estradiol exhibit pre-pubertal rises approximately 3 to 5 wk before the first egg is laid (Yoav et al., 1998). Increased levels of progesterone, approximately 1 wk before SM, promote rapid growth of large yellow follicles (Etches, 1996a). Sexual maturation may depend more on hypothalamic maturation than on meeting carcass thresholds as a result of nutrient intake (Renema et al., 1999; Robinson et al., 2001). *Ad libitum* feeding enhanced the level of LH and follicle stimulating hormone (FSH) compared to restrictive feeding in a modern broiler breeder strain (Renema et al., 1999).

Surprisingly, some strains of broiler breeders, when fed *ad libitum* show no difference in the timing of SM compared to feed restricted strains.

Immature ovarian follicles (< 5 mm in diameter) have been shown to be steroidogenically active (Robinson and Etches, 1986). Estrogen production from the small follicles increases beyond base levels approximately 3 to 5 wk before SM (Yoav et al., 1998). As the follicle matures through the hierarchy, it loses the ability to produce a high concentration of estradiol (Robinson and Etches, 1986). Large yellow follicles have been shown to produce relatively low amounts of estradiol *in vitro* compared to small follicles (Yu et al., 1992c). Small follicles presumably initiate the pre-pubertal rise in concentration of estradiol before SM, although the control in the onset of this rise most likely originates from the hypothalamus.

Estrogen is responsible for secondary sexual development in the domestic chicken. The growth of the comb is a physical sign that the time of SM is approaching (Etches, 1996a). The relationship between plasma estrogen and comb growth has previously been demonstrated. Combs size of broiler and layer chickens, as measured by area, increased 8wk before SM and their development correlated with increased plasma estrogen (Eitan et al., 1998). In broiler breeder pullets, comb height and length increased 5 wk before the first egg (Fattori et al., 1993). Comb size (length, height, and area) increased as plasma estradiol concentration increased and the most notable growth occurred after photostimulation (Joseph et al., 2002).

Bird carcass conformation measurements may also provide an estimation of SM. Reports of relationships between conformation measurements and sexual maturation are scarce in published literature. Skeletal growth has been examined, but studies have focussed more on the effects on the growth of the shank (Leeson and Summers, 1984; Leili and Scanes, 1998) and keel bones (Hudson et al., 2000) when the diet varies in CP. Other research has shown that broiler breeder strains had similar shank and keel lengths at first egg (Joseph, 2000). Energy allocation shifts from skeletal growth to reproductive growth as birds chronologically age and fat deposition increases (Robinson et al., 1996).

A high degree of BW uniformity in flocks is optimal for achieving sexual maturation at a uniform chronological age (Hudson et al., 2001). Previously, feed allocation has been shown to directly affect the timing of SM. Broiler breeders with higher BW were sexually mature sooner than those birds with lower BW (Robinson and Robinson, 1991; Yu et al., 1992b; Robinson et al., 1998; Hocking and Robertson, 2000). Broiler breeder producers strive to minimize differences in BW between birds in the same flock. Physiological growth of the reproductive organs is presumably similar when birds have average body weights that are close to target values.

The first objective of this study was to select pullets at 18 wk, assign them to three BW groups, and identify their body conformation before SM. More data on body conformation are required, as an addition to BW, to identify pullets that varying in fleshing content and frame size. Pullets that receive a lower or higher amount of feed compared to those on target levels may not be efficient reproducers. The second objective was to fine tune the level of feed intake from 18 wk of age to SM, and the time required for the birds to be reproductively mature. The third objective was to examine if a hatching supplement fed to chicks for a 30- h period after hatching had any effect on carcass conformation measurements at a later age. The effects of a hatching supplement on subsequent BW have been shown to diminish by 18 wk of age (Chapter 3) and effects on carcass conformation measurements after this time were not expected.

5.2 MATERIALS AND METHODS

Stocks and Management

Classic [1] broiler breeder eggs were shipped by the breeder company and hatched individually so that egg and chick characteristics such as egg shell quality, egg set weight, egg transfer weight, and initial hatching weight could be recorded for each bird. Materials and methods used for hatching can be found in Chapter 3. After hatching, a total of 856 chicks (428 chicks / treatment) were assigned to either an OASIS (Chicks receiving Oasis ®[2]) or a CONTROL (chicks receiving no hatching supplement) treatment group.

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[1] Aviagen North America, Huntsville, AL, USA, 35805.

Pullets were reared in a light tight facility where the photoperiod consisted of continuous light (24L: 0D; L : hours of light; D : hours of dark) for the first 3 d followed by 8L: 16D until 18 wk of age. Pullets were photostimulated at 22 wk of age with a photoperiod of 15 L: 9 D. Pullets were fed as follows: starter diet until 4 wk of age; grower diet from 4 to 22 wk of age; and a breeder layer diet from 22 wk until the first egg was laid (Table 5-2). Pullets were fed *ad libitum* until 3 wk of age at which time feed restriction was imposed [3]. All dietary nutrients were fed to meet or exceed NRC requirements (NRC, 1994). At 18 wk of age, 242 pullets were selected based on average BW and assigned to one of three BW groups. Standard (STD) were at target BW suggested by the Arbor Acres Broiler Breeder management guide (Anonymous, 2000); Low (LOW) birds were 15 % lighter than STD birds; High (HIGH) birds were 15 % heavier than STD birds. The numbers of birds placed in each BW group were as follows: STD (n = 82), LOW (n = 81) and HIGH (n = 79). Following caging, feed allocation of LOW and HIGH birds were adjusted to maintain a similar rate of gain to the STD birds on the target BW growth curve.

Time of SM was defined as the average number of days from hatching to first oviposition for each BW group. Birds that laid either normal (hard-shelled) and defective egg types (soft-shelled or membranous) were considered to have become sexually mature. Weight of the first egg was recorded. At SM, birds were killed by cervical dislocation and selected carcass components and reproductive organs were removed and weighed. Carcass contents included the breast muscle (*Pectoralis major and minor*), liver and abdominal fat pad (including fat surrounding the gizzard). Reproductive organs removed were the ovary (yellow follicles and stroma) and the oviduct (including the shell gland). The ovary was further categorized by the number of healthy or atretic large yellow (LYF >10 mm) and small yellow follicles (SYF 5 - 10 mm). Atretic follicles were defined as follicles that had a discolored or shrunken appearance (Gilbert et al., 1983). Total follicular weight was defined as the weight of all LYF and omitted the weight of all atretic follicles attached to the ovary. Large yellow follicles were further classified as single or paired and their position was dependent on the weight of the associated LYF. All LYF > 3.0 g were considered to be paired only if the difference between the follicles was ≤ 1.0 g. The remaining follicles < 3.0 g were paired only if the difference between the follicles was ≤ 0.5 g. This method of classification was chosen because follicles at the bottom of the hierarchy (< 3.0 mm in diameter) were assumed to be too small to predict whether or not these follicles would ovulate in multiple sets at the time of ovulation. The number of positions was defined as the total number of follicles in the ovary where paired follicles were counted as one position. The number of hierarchies was calculated as the total number of LYF divided by the number of positions.

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[2] Novus International Incorporated, St. Louis, MO, USA, 63141.

[3] Feed allocation during rearing was calculated by feed requirement per day x 7 / 5 days. Non feed days were Tuesdays and Saturdays.

The *Pectoralis major* muscle and slice samples were digitally photographed using image analysis software [4]. Further detail on the methodology of measurements recorded from the entire *P. major* muscle and slice samples is provided in Chapter 4 (Figures 4-2 and 4-3). Live bird measurements were collected on a weekly basis from 18 wk until SM. These measurements were thoracic width, thoracic circumference, shank length, keel length and comb measurements such as length, height and area. Chapter 4 (4.2 Materials and Methods) outlines the methodology in more detail. Each bird's comb was photographed with a digital camera. Comb measurements (length, height, and area) were collected using an image analysis software program [4]. Comb height was measured as the distance from the base of the comb to the top of the tallest peak. Comb length was measured as the distance between the first spike and the end of the comb. Comb area was calculated from the image analysis software program.

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[4] Northern Exposure, Empix Imaging Inc., Mississauga, ON, Canada, L5L 5M6.

A sub-sample of birds within the experiment (n = 36 where n = 12 of LOW, STD or HIGH) were further measured for breast muscle thickness as well as plasma estradiol-17β concentration and plasma lipid content. Data for this population of birds were collected weekly from 19 wk of age until SM. The sub-sample was randomly chosen from the total population of birds in order to minimize the handling stress in the experiment. Breast muscle thickness was measured using real time ultrasonography [5]. Each bird was externally marked using a permanent black marker with four points of measurement on the breast for repeated measures. For further details on the ultrasound procedure see Chapter 4 and Figure 4-1.

Blood was collected from the brachial vein between 1300 and 1500 h into heparinized vacutainer tubes, centrifuged for 15 minutes at 4 ^{0}C, and stored at – 20 ^{0}C until further testing. Plasma estradiol-17β concentrations were quantified by age and BW using radioimmunoassay [6] (Renema et al., 1999). Each plasma sample was measured in duplicate where 100 μL was placed in each antibody-coated tube. Sensitivity of the assay was less than 5.0 pg / mL where the mean within assay CV was 2.86 % and the mean between assay CV was 7.62 %. The test was highly specific for estradiol-17β and cross reactivity with other compounds in the sample is low. Lipid extraction was performed on the same plasma samples using Folch's Quantitative Lipid procedure. Plasma lipid was measured in duplicate for each bird sample. This experiment was conducted in accordance with the principles and guidelines set by the Canadian Council on Animal Care (Olfert et al., 1993).

Statistical Analysis

The main treatment effect of BW group (LOW, STD, and HIGH) on carcass, reproductive and BW variables were tested by a one-way ANOVA (SAS Institute Inc., 1999). A

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[5] Model SSD–500, Aloka ultrasound diagnostic equipment, Aloka Co. Ltd., Tokyo, Japan, 181-8622.
[6] Coat-A-Count Kit Number TKE25, Dagnostic Products Corp., Los Angeles, CA, USA, 90045-5597.

3 X 2 factorial design was used to examine the growth rate from the morphology data (breast muscle thickness, shank and keel length, thoracic width, thoracic circumference and comb measurements). The General Linear Models procedure of SAS ® tested the main effects of hatching treatment (OASIS and CONTROL) and BW group (LOW, STD and HIGH) and generated overall values, absolute gain and percent gain in growth of all conformation parameters from 18 wk of age until SM (SAS Institute Inc., 1999). The error variation for the BW groups was the variation between each individual bird. Rate of growth for conformation, comb and ultrasound measurements was reported in mm / wk for all parameters. P-values for differences for the LS-means were generated by SAS ® when the main effects and interactions were significant (SAS Institute Inc., 1999). Pearson correlation procedure of SAS ®was used to determine relationships between conformation measurements and the time required for SM (SAS Institute Inc., 1999). Total bird numbers per BW group for statistical analysis decreased to n = 80 (STD); n = 76 (LOW) and n = 78 (HIGH) because eight birds with broken wings and a pendulous crop were culled during the cage period. The correlation coefficients and subsequent probabilities presented in Table 5-9, represent values up to and including 29 wk of age. The data for week 30 and 31 are not presented as very few birds remained in the population at that time (n = 3 in the LOW BW group only). The number of pullets in each BW group decreased as birds reach SM (Table 5-1).

Line plots were generated using SigmaPlot software [7]. The means and the standard errors of the means were generated using PROC MEANS of (SAS Institute Inc., 1999). All conformation data was presented by line plots and values after 25 wk of age (SM was first initiated at this time), denotes values for birds that still remained in the experiment. Unless otherwise stated, significance was tested at $P < 0.05$.

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[7] SigmaPlot for Windows Version 3.03, Jandel Corporation, San Rafael, CA, USA, 94912.

5.3 RESULTS AND DISCUSSION

Body Weight from 18 wk to Sexual Maturity

Average weekly BW differed significantly between the BW groups up to 29 wk of age (Table 5-3). The percent of BW gain per week was higher in LOW birds compared to their heavier counterparts (HIGH = 6.32 %; STD = 6.89 %; LOW = 7.73 % $P = 0.0001$; data not shown). The higher BW gain for LOW birds is in agreement with BW gain findings of Hudson et al. (2001). Birds in LOW, STD, and HIGH groups were fed to maintain their respective BW curves throughout the entire experiment period. Even though LOW weight birds had less feed allocated to them, based on the BW gain data, it appears that the amount of feed available was sufficient as they gained BW and reached SM.

Carcass Characteristics at Sexual Maturity

The LOW birds had a smaller frame size compared to heavy birds, as indicated by shorter shank and keel lengths at SM (Table 5-4). At SM, the variation in thoracic growth, measured by width and circumference, was similar in LOW and STD birds and higher in HIGH birds. The length:width ratio, a calculation that represented the ratio of keel length to thoracic width, was lowest in the HIGH BW group (LOW = 1.88, STD = 1.88, and HIGH = 1.83). These results indicate that heavier birds grew larger skeletal frames and broader thoracic cavities. It is not clear whether the broader circumference in HIGH birds was due solely to breast muscle mass or if these birds had a wider rib cage. However, heavier birds had significantly greater breast muscle weights at SM, which may indicate that these birds had more fleshing (Table 5-4). A higher degree of fleshing in the HIGH birds suggests that growth was advanced in these birds and that maturation of the reproductive organs was approaching sooner than in LOW weight birds. The HIGH birds also had heavier fat pads (absolute weight and % of BW) compared to STD and LOW birds (Table 5-4) and agrees with the data of Renema et al. (1999). Robinson et al. (1996)

suggested that energy partitions more to fat deposition as breeder pullets age. A higher amount of body fatness was evident in the HIGH birds and may indicate that skeletal growth slowed down as reproductive maturation began. Concomitant increases of plasma estradiol concentration in the HIGH birds may further indicate that HIGH birds began reproductive maturity sooner than LOW birds (Figure 5-12).

The absolute value of liver weight differed significantly across the BW groups (HIGH = 56.3 g, STD = 53.2 g, and LOW = 50.3 g) but liver size was similar when expressed relative to BW. Renema et al. (1999) demonstrated that broiler breeders fed higher amounts of feed in a restricted program had heavier livers, but only compared to birds that were in the lower feed treatment. Relative liver weight was also not different between BW groups and agrees with results of the present study. Renema et al. (1999) suggested the reason for higher liver weights in HIGH birds was partly due to higher concentration of liver lipid in these birds but this result was only found in *ad libitum* fed birds, indicating a feed effect. Bjerstedt et al. (1995) also found heavier fat pad and liver weights in Single-Comb White Leghorns fed *ad libitum* compared to feed restriction.

Breast muscle weight was not different when expressed as a percentage of total BW (HIGH = 16.6 %, STD = 16.4 %, and LOW = 16.3 %). Image analysis measurements of the dissected breast muscle revealed smaller and narrower breast muscles in LOW birds compared to STD and HIGH birds (Table 5-5). The measurements to indicate these results were area, half line and the widest line from the whole breast as well as the length measurement from the long slice and the area and length measurements from the wide slices.

Reproductive Characteristics at Sexual Maturity

Birds in the lowest BW group came into SM an average of 7.6 d later than birds in the highest BW group (LOW = 190.1 ± 1.0 d and HIGH = 182.5 ± 1.0 d). The onset of SM was initiated first by birds in the HIGH BW group and was completed first in these birds (Figure 5-1). Birds fed according to the breeder company's recommended BW curve (STD birds) were sexually mature at an average of 186.4 ± 1.0 d, with a mature BW of 3,105 g as has been reported previously (Joseph, 2000).

The LOW birds also had significantly lower ovary weight than did HIGH birds but were similar in weight to STD birds (LOW = 61.5 g, STD = 62.8 g, and HIGH = 64.5 g, $P = 0.043$). Birds with HIGH BW had heavier ovary weights (4.7 % greater than LOW birds), the heaviest livers (10.7 % greater than LOW birds) and the highest estradiol-17β concentrations (Figure 5-12). Robinson et al. (1998) demonstrated that underweight broiler breeders had lower ovary weights at SM. Even though all birds were feed restricted in this experiment, heavier liver weights corresponded to heavier ovary weights, suggesting a relationship between the liver and the ovary. Maturing ovarian follicles sequester yolk produced by liver, a process known as lipogenesis (Etches, 1996b). The production of estradiol from small follicles stimulates lipogenesis, albumen, and calcium absorption during egg and shell formation (Nitta et al., 1991; Etches 1996b). The total weight of all LYF was highest in the HIGH BW group compared to the LOW BW group and contributed to heavier ovary weights in the HIGH BW group. Higher total LYF weights in combination with larger livers suggests a higher amount of yolk production in the liver followed by transportation to the maturing follicles. However, mean weight of the first follicle was similar between BW groups (Table 5-5). A similar weight in the first LYF was reflected in the weight of the first egg, as this was similar among all BW groups (LOW = 43.3 ± 0.6 g, STD = 43.0 ± 0.6 g and HIGH = 43.4 ± 0.6 g, $P = 0.9176$).

The number of large yellow follicles (LYF > 10 mm) differed significantly among BW treatments (Table 5-6). Birds in the LOW group had 6.89 LYF compared 7.58 LYF in the HIGH BW group. Renema et al. (1999) reported higher numbers of LYF using Shaver Starbro broiler breeders (LOW = 8.8 and HIGH = 8.9). *Ad libitum* feeding was implemented in their experiment and most likely accounts for higher LYF numbers. Restrictive feeding has been shown to place a limitation on follicular recruitment (Renema et al., 1998). However, low numbers of LYF in the LOW BW group suggest lower egg production rates (Robinson and Robinson, 1991). Hens in the HIGH BW group had a higher number of LYF that were in multiple sets (HIGH = 3.42) as well as a higher percent of multiple sets (HIGH = 42.9 %) compared to STD and LOW birds. Double yolk eggs are a result of multiple ovulation of LYF from the ovary. Yu et al. (1992c) suggested that multiple ovulations are caused from the increased production of progesterone by the second largest mature follicle. *Ad libitum* feeding resulted in increased progesterone profiles in the F2 follicle, to levels that were similar to the F1 follicle. Body weight has been related to follicle number ($r^2 = 0.363$, Yu et al., 1992a). Higher BW has been associated with erratic laying patterns and higher numbers of defective eggs (Yu et al., 1992b). Incidences of defective eggs and erratic ovulations reduce settable egg production. The results in the present experiment indicate that HIGH BW birds would have most likely had higher egg production rates but these rates would be compromised by an increased incidence of double-yolk eggs.

Kwakkel et al. (1995) used a multiphasic growth model to identify growth patterns (absolute and relative growth) of reproductive organs in Single Comb White Leghorns. Gompertz and Kwakkel growth models are non-linear models that are limited because they consist of age functions. In the present experiment reproductive data were forced to fit to a linear curve using the General Linear Models procedure (SAS Institute Inc., 1999). The use of this approach helped to eliminate the variation that would have occurred if age were included in the model. Data generated from the linear approach were meaningful. However, it would be more meaningful to fit the data to a non-linear, biological growth curve. Currently, a non-linear model that excludes the function of age is not available in poultry science literature.

Body Growth as Described by Conformation Measurements

Bone and Muscle Measurements Growth of the shank and keel bones paralleled changes in BW (Table 5-7). Birds in the LOW BW group had the lowest shank and keel values. Average weekly shank and keel measurements differed relative to BW (Figure 5-2 and Figure 5-3). Similarly, the average thoracic width and circumference measurements differed relative to BW (width: 75.6 mm, 72.4 mm, and 69.3 mm; circumference: 343.1 mm, 333.8 mm, and 322.9 mm for HIGH, STD and LOW, respectively). Average weekly thoracic width and circumference measurements also varied relative to BW (Figure 5-4 and Figure 5-5). The gain in thoracic width was similar among the BW treatments, although the gain in thoracic circumference was higher in LOW birds compared to STD and HIGH birds (HIGH = 3.54 %, STD = 3.58 %; LOW = 3.96 %). Birds in the LOW BW group exhibited a higher rate of gain (%) in keel length, thoracic width and circumference measurements compared to STD and HIGH birds. At the beginning of the experiment, the LOW birds were smaller in BW and frame size compared to STD and HIGH birds. The conformation data indicated that the LOW birds grew at a much faster rate than STD or HIGH birds.

Birds chosen for this experiment were moved from floor pens to individual cages at 18 wk of age. However, in a flock environment, birds are typically managed without separation. Competition may prevent fleshing in a bird with low BW compared to a bird with a higher BW before reproductive maturation. Lower weight birds may continue to convert energy into breast muscle even after photostimulation (Chapter 4). After a photostimulatory cue, it may take up to 4 wk before the last bird in a flock is sexually mature. Birds with smaller conformation measurements would most likely "flesh out" at an older chronological age. In this experiment, LOW birds gained thoracic width and circumference at a higher rate than STD or HIGH birds. However, birds in the LOW BW group had insufficient time to grow in body conformation before their heavier counterparts reached SM. Subsequent egg production rates, persistency of peak production and even fertility are negatively affected by non-uniform sexually maturation in flocks (Robinson et al., 1999).

Ultrasound thickness measurements indicated that the upper section of the breast was significantly thicker in HIGH and STD birds compared to LOW birds (23.9 mm, 23.0 mm, and 20.6 mm, respectively). Other ultrasound measurements were similar. Breast muscle thickness of the upper and lower breast measurements increased with age (Figure 5-6 and Figure 5-7). The curves of average measurements in time indicated that LOW birds had thinner breast muscle in the upper and lower sections, whereas growth rate was similar for STD and HIGH birds throughout the experimental period. The curve of breast muscle thickness for LOW BW birds (Figure 5-6) showed a "spike" at 25 wk of age followed by a lower value at 26 wk of age. This is because several birds in the LOW group had thicker upper breast sections at 25 wk of age. However by 26 wk of age, these birds had reached SM and were not included in the data at 26 wk of age.

Weekly shank length measurements from 18 to 31 wk of age were not related to the age of SM (Table 5-9). Keel length showed a stronger correlation to age at SM than shank length. However, the correlation for weekly keel lengths decreased as pullets reached SM. Skeletal growth is more strongly associated with BW (Lilburn et al., 1989; Bjerstedt et al., 1995) rather than reproductive maturation (Joseph, 2000). Sexual maturation was better associated with weekly carcass conformation measurements of BW, thoracic width, thoracic circumference and comb size (Table 5-9). The thoracic width ranged between r = - 0.23 to r = - 0.33 from 18 to 24 wk of age indicating that broader hens came into production sooner.

Comb Size Image analysis indicated that comb measurements (length, height and area) differed among BW groups (LOW, STD and HIGH) and with hatching treatment (OASIS and CONTROL; Table 5-8). Average weekly comb area (absolute and gain), increased linearly with BW, whereas length and height measurements were greatest in HIGH birds compared to STD and

LOW birds. Comb length (Figure 5-8), comb height (Figure 5-9) and comb area (Figure 5-10) remained low until 21 wk of age. After this time the measurements increased until SM. Image analysis is a fairly new approach in the poultry science literature for measuring comb growth in breeders. However, image analysis has been shown to provide objective measurements of comb growth (Joseph et al., 2002).

It has been suggested that plasma estradiol-17β concentration is related to comb size in female birds (Fatorri et al., 1993; Eitan et al., 1998; Joseph et al., 2002). *Ad libitum* fed broiler breeders had a 2-fold increase in comb size at SM compared to feed restricted females (Eitan et al., 1998). In this experiment estradiol-17β concentration increased after photostimulation, whereas combs began growing at 18 wk of age (Figure 5-12). Comb growth was evident 5 wk (Fatorri et al., 1993) and 8 wk (Eitan et al., 1998) before the first egg was laid. These results suggest that comb growth occurred before photostimulation despite low estrogen concentration. Body weight positively correlated with comb growth (Eitan et al., 1998) and may be a stronger indicator of SM compared to measuring plasma estradiol concentrations. Repeated blood collection and a radioimmunoassay (RIA) test are required to measure plasma estradiol concentration.

Weekly measurements of comb length, height, and area demonstrated a strong correlation with the time to SM as has been previously reported (Joseph et al., 2002). Although comb growth related well to the day of first egg, the use of image analysis on a farm is impractical. Measuring comb growth with a ruler is as effective as image analysis (Joseph et al., 2002) but not as objective for scientific experiments. Much research has focussed on "thresholds" that must be reached before sexual maturation occurs (Brody et al., 1984; Soller et al., 1984; Dunnington and Siegel, 1984). The data in this experiment have proposed an estimation of timing to SM, rather than to suggest that average values in carcass conformation measurements must be obtained before sexual maturation occurs. In this experiment, the thoracic circumference measurement related well to timing of the production of first egg. This measurement was easy to apply and may be the most practical in comparison to other carcass conformation measurements evaluated in this study.

Plasma Lipid and Estradiol-17β Concentrations

Plasma lipid profiles for each BW group remained similar from 19 to 24 wk of age (Figure 5-11). At 25 wk of age, HIGH birds had a higher lipid concentration than STD and LOW birds (17.1 mg / mL, 8.6 mg / mL, and 6.1 mg / mL, respectively). The HIGH birds had heavier fat pads at SM compared to STD and LOW birds, which may account for the plasma lipid differences at 25 wk of age. Changes in the slopes of the plasma lipid concentration curves for each BW treatment could have been caused by changes in the amount of feed allocated. Plasma lipid concentrations showed a 2-wk delay in the response to photostimulation at 22 wk of age. Large yellow follicles most likely began maturing at 24 wk of age.

Plasma estradiol-17β concentrations between LOW, STD, and HIGH BW groups (n = 36) differed significantly at 20, 26 and 27 wk of age (Figure 5-12). At 20 wk of age, HIGH (29.6 pg / mL) birds had significantly higher levels than STD (20.6 pg / mL) or LOW (14.5 pg / mL) birds. Elevated plasma estradiol concentrations from birds in the HIGH BW group could suggest advanced ovarian development (Renema et al., 1999) at 20 wk of age. Birds in the HIGH group were sexually mature before STD and LOW birds (25 wk) and a loss in bird numbers after this time may not represent true differences at 26 and 27 wk of age. The hens in this experiment, regardless of BW treatment, had basal levels of estradiol-17β concentration that were less than 30 pg / mL before photostimulation. After a photostimulatory cue, levels increased to between 70 and 90 pg / mL. Photostimulation increases the production of plasma estrogen from small follicles (Robinson and Etches, 1986). Steep slopes from the curves between 22 to 23 wk of age suggest a rapid response to photostimulation. After 23 wk of age, however, the slopes of the profiles were not as steep suggesting a dampened response after 23 wk. Even though photostimulation caused an immediate response, the maximal response after 22 wk of age seemed to be influenced by BW. The HIGH BW birds reached maximum estradiol concentration at 237 pg / mL, STD at 206 pg / mL and LOW at 195 pg / mL suggesting that BW affected the level of plasma estrogen at SM, also reported by Renema et al. (2001).

Hatching Treatment

Hatching treatment (OASIS or CONTROL) had no effect on weekly BW, carcass or reproductive characteristics at SM (data not shown). In the ultrasound measurements, OASIS birds had a thicker upper breast muscle measurement compared to CONTROL birds (23.14 mm vs. 21.83 mm; $P = 0.0124$; data not shown). Birds in the OASIS treatment had lower comb length and area measurements compared to the CONTROL (Table 5-8). The reasons for the results in the hatching treatment are unknown. Chapter 3 showed that a hatching supplement had no effect on BW after 4 wk of age and BW uniformity after 3 wk of age (Chapter 3).

Timing of Photostimulation for Reproduction

It is critical that a broiler breeder pullet has gained flesh content before photostimulation. A well-fleshed bird generally has adequate muscle coverage in relation to skeletal size. Pullets that are well-fleshed before photostimulation typically become efficient reproducers (Don Copeland, Aviagen North America, Huntsville, Alabama, 35805, Personal Communication, 2001). All the pullets in this study were photostimulated at 22 wk of age. Before photostimulation, pullets in the LOW BW group had limited mass and comb size compared to STD and HIGH BW birds (Table 5-10). Plasma estradiol-17β concentration increased by 89.3 % between photostimulation and SM at 190.1 d for birds in the LOW BW group.

Comb area increased by 54.7 % for STD birds between the time of photostimulation and SM at 186.4 d (Table 5-11). Plasma estradiol-17β concentration increased in these birds by 86.5 % during the same period. Pullets in the HIGH BW group had the greatest mass and comb size before photostimulation (Table 5-12). Plasma estradiol-17β concentration increased by 86.3 % in HIGH BW birds between photostimulation and SM at 182.5 d. Comb area increased by 56.3 % during the same period. Comb size (length, height, and area) increased in time for all birds in the study. Similarly, plasma estradiol-17β concentration increased with time until bird numbers per BW group resulted in great amounts of variation as a result of SM. Previous research has shown a positive correlation between circulating estrogen concentration and comb size (Eitan et al., 1998; Joseph et al., 2002). Sexual characteristics are important external indicators of reproductive maturity in chickens. Similar appearance between breeders within the same flock may be the best indication that internal reproductive growth and condition is also similar. Although photostimulation increased the concentration of estrogen in all birds, pullets in the LOW BW group had lower circulating estradiol-17β concentration at photostimulation.

Smaller conformation measurements and thinner breast muscle in LOW BW pullets indicated that these birds did not have as much flesh development at photostimulation compared to birds in the STD or HIGH BW groups. The photostimulatory cue may have caused LOW BW pullets to allocate nutrients to muscle and reproductive maturation proportionately. Whereas HIGH BW birds allocated more energy to reproductive development indicated from larger livers, ovaries, more LYF, and heavier fat pads. Smaller conformation (breast muscle and skeletal frame) suggests that LOW BW birds did not achieve the chronological age required for SM in comparison to STD or HIGH BW birds. Examining the gain in comb size may help indicate when pullets are ready for photostimulation. Proper data collection (quantitative measurements) in monitoring breast muscle gain may yield a reliable indication of optimal photostimulation threshold.

This experiment examined carcass conformation of meat-type breeder hens from three BW groups as they reached SM. Weekly thoracic circumference and comb measurements (length, height, and area) demonstrated positive and strong correlation with SM. Muscle development in low weight birds was not completed before SM, as indicated by thinner and narrower breast values, unlike their heavier counterparts. Bird BW affected age of SM, as low BW birds took nearly eight more days to mature sexually compared to the heaviest birds. Pullets rapidly responded to a photostimulation cue as denoted by increased estradiol-17β concentration after 22 wk. Heavy birds in this experiment had heavier fat pads, breast muscles, livers, ovaries, and a higher number of LYF. Birds with HIGH BW also had a greater potential to ovulate LYF in multiple sets, a factor that could contribute to lower production of settable eggs. Birds with LOW BW had fewer LYF attached to the ovary, which suggest sub-optimal reproductive function. Contrary to expectations, birds previously exposed to a hatching supplement displayed lower comb size and breast muscle thickness.

Data in this experiment indicated that timing of sexual maturation differed was not similar in birds that were fed using different BW curves. Plasma estradiol-17β concentrations, liver weight, ovary weight and the number of LYF were enhanced in birds with HIGH BW. These birds also showed growth in their reproductive organs first, suggesting that nutrients were allocated to sexual maturation rather than breast muscle development after photostimulation (Chapter 4). Birds with low BW contribute to lower flock uniformity and decrease the persistency of peak production (Leeson and Summers, 1997). In this study, photostimulation at 22 wk of age was appropriate for pullets in the STD and HIGH BW groups but not for pullets in the LOW BW group. Small-framed birds may reach SM at a slower rate and during production may continue to allocate nutrient resources to both reproduction and growth.

Detecting the timing of reproductive maturity in broiler breeder pullets is challenging. Previous literature has shown that feed allocation does not fully account for the timing of SM in female breeders. *Ad libitum* feeding increases the concentrations of LH and plasma estradiol (Renema et al., 1999). Fine-tuning the time of SM is also complicated by variation in reproductive maturation patterns among existing strains (Renema et al., 1999). The reason for variation in the timing of SM may be most affected by the hypothalamus because its maturation must take place before the onset of reproductive maturity (Renema et al., 1999; Robinson et al., 2001). This study showed that fleshing content and frame size varied relative to BW. Pullets in the LOW BW group lagged in their conformation compared to STD and HIGH birds by the time they were photostimulated. Estrogen concentrations increased with the gain in comb size for all pullets in the experiment. Average BW for a breeder flock may not provide enough information on the optimal time of photostimulation. Data collection, such that BW data is combined with conformation data of fleshing content and frame size, would help indicate optimal photostimulation threshold and benefit reproductive performance.

TABLE 5-1. Number of broiler breeder pullets in each BW group during the experiment where a decrease in number represents pullets that had reached sexual maturity

	Age (wk)													
	18	19	20	21	22	23	24	25	26	27	28	29	30	31
BW group[1]	Total population[2]													
LOW	76	76	76	76	76	76	76	75	64	38	15	5	2	2
STD	80	80	80	80	80	80	80	80	54	23	8	3	1	1
HIGH	78	78	78	78	78	78	78	69	36	15	3	0	0	0
	Sub-population[3]													
LOW	N/A	12	12	12	12	12	12	12	11	9	3	2	0	0
STD	N/A	12	12	12	12	12	12	12	7	4	3	0	0	0
HIGH	N/A	12	12	12	12	12	12	11	3	3	0	0	0	0

[1] BW group : STD birds on target according to Arbor Acres Breeder Management Guide; LOW birds 15 % lower in BW compared to STD; HIGH birds 15 % higher in BW compared to STD birds.

[2] Total population : n = 234 birds for analysis of BW, comb and conformation measurements, ovarian, carcass and breast muscle characteristics.

[3] Sub-population : n = 36 birds for analysis of plasma estradiol-17β and plasma lipid concentration and breast muscle thickness.

TABLE 5-2. Ingredients and nutrient composition of female broiler breeder starter, grower, and breeder layer diets

	Starter[1]	Grower[2]	Breeder Layer[3]
	kg		
Diet Ingredients[4]			
Broiler premix[5]	5.00	5.00	5.00
Wheat shorts	75.00	150.00	N/A
Oats	50.00	125.00	N/A
Soymeal	173.40	73.70	187.76
Corn	141.40	164.40	414.70
Wheat	442.30	344.20	252.93
Barley	50.00	100.00	N/A
Tallow	20.00	0.70	16.30
Iodized salt	3.84	3.30	5.68
Lysine	0.31	1.62	N/A
Methionine	1.41	1.25	0.94
Limestone	16.50	17.20	79.30
Choline premix[6]	5.00	5.00	5.00
Biofos	15.80	8.60	N/A
Monensin	0.75	0.50	N/A
Nutrient Composition[7]			
Moisture (%)	11.4	11.1	11.6
Ash (%)	5.08	4.76	10.8
Crude protein (%)	17.8	15.7	19.4
Crude fiber (%)	3.4	4.4	2.4
Metabolizable energy (kcal / kg)	2880	2753	2880
Crude fat (%)	3.6	3.0	3.1
Calcium (%)	0.90	3.48	3.12
Phosphorus (%)	0.67	0.83	0.70
Potassium (%)	0.77	0.55	0.72
Magnesium (%)	0.16	0.16	0.17
Sodium (%)	0.15	0.12	0.13
Salt (%)	0.37	0.32	0.33

[1] Starter diet was fed from 0 to 4 wk of age.

[2] Grower diet was fed from 4 to 18 wk of age.

[3] Breeder layer diet was fed from 18 wk of age to the end of the trial.

[4] Diet ingredients were mixed to produce 1000 kg of feed.

[5] Broiler premix provided per kilogram of diet: vitamin A (retinyl acetate), 10,000 IU; cholecalciferol, 2,500 IU; vitamin E (DL-α-tocopheryl acetate), 35 IU; vitamin K, 2.0 mg; pantothenic acid, 14 mg; riboflavin, 5.0 mg; folacin, 0.8 mg; niacin, 65 mg; thiamine, 2.0 mg; pyridoxine, 4.0 mg; vitamin B12, 0.015 mg; biotin, 0.18 mg; iodine, 0.5 mg; Mn, 70 mg; Cu, 8.5 mg; Zn, 80 mg, Se, 0.1 mg; Fe, 100 mg.

[6] Choline chloride provided at 100 mg / kg.

[7] All nutrients listed are based on analyzed values.

TABLE 5-3. Average weekly BW and daily feed allocation for broiler breeder pullets in LOW, STD, or HIGH BW groups

	Age (wk)													
	18	19	20	21	22	23	24	25 [2]	26	27	28	29	30	31
BW group[1]	BW (kg)													
n	234	234	234	234	234	234	234	224	154	76	26	8	3	3
LOW	1.49^{c}	1.69^{c}	1.84^{c}	1.96^{c}	2.13^{c}	2.23^{c}	2.38^{c}	2.54^{c}	2.70^{c}	2.87^{c}	3.07^{b}	3.16^{b}	3.20	3.35
STD	1.75^{b}	1.93^{b}	2.09^{b}	2.22^{b}	2.39^{b}	2.49^{b}	2.63^{b}	2.79^{b}	2.97^{b}	3.15^{b}	3.31^{b}	3.49^{a}	3.72	3.69
HIGH	2.01^{a}	2.18^{a}	2.34^{a}	2.47^{a}	2.64^{a}	2.74^{a}	2.90^{a}	3.08^{a}	3.24^{a}	3.44^{a}	3.68^{c}	.	.	.
SEM	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.01	0.03	0.16	0.08	0.05	0.18
Probability	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0033	0.0117	0.1727	0.2453
	Feed allocation (g / bird / day)													
LOW	84	86	90	98	100	104	110	115	119	119	119	119	119	119
STD	90	92	97	105	108	112	118	124	128	128	128	128	128	128
HIGH	96	99	104	112	116	120	126	133	137	137	137	.	.	.

[a,b,c] Means within a column with no common superscript differ significantly at $P < 0.05$.

[1] BW : STD birds on target according to Arbor Acres Breeder Management Guide; LOW birds 15 % lower in BW compared to STD; HIGH birds 15 % higher in BW compared to STD birds.

[2] Wk 25 : number of birds / BW group decreased after this time due to SM.

TABLE 5-4. Bird conformation and carcass characteristics at sexual maturity for female broiler breeders in LOW, STD or HIGH BW groups

		BW group[1]			
Parameter	LOW	STD	HIGH	SEM	Probability
	---------------- Mean	----------------	----------------		
Processing BW (g)	2920.1^{c}	3105.0^{b}	3303.7^{a}	25.7	0.0001
Breast muscle weight (g)[2]	475.9^{c}	515.0^{b}	542.5^{a}	6.5	0.0001
Breast muscle weight (%)	16.3	16.4	16.6	0.1	0.2482
Fat pad weight (g)	85.4^{b}	91.4^{b}	109.6^{a}	3.2	0.0001
Fat pad weight (%)	2.94^{b}	2.90^{b}	3.31^{a}	0.09	0.0026
Liver weight (g)	50.3^{c}	53.2^{b}	56.3^{a}	1.1	0.0007
Liver weight (%)	1.73	1.72	1.70	0.03	0.8626
Shank length (mm)	105.5^{c}	107.5^{b}	109.0^{a}	0.4	0.0001
Keel length (mm)	153.1^{b}	157.6^{a}	159.0^{a}	0.7	0.0001
Thoracic width (mm)	82.2^{b}	83.9^{b}	87.3^{a}	0.8	0.0001
Thoracic circumference (mm)	335.9^{b}	344.9^{ab}	352.7^{a}	4.4	0.0273
Length:width ratio[3]	1.88^{b}	1.88^{b}	1.83^{a}	0.02	0.0311

$^{a, b, c}$ Means within a row with no common superscript differ significantly at $P < 0.05$.

[1] BW : STD birds on target according to Arbor Acres Breeder Management Guide; LOW birds 15 % lower in BW compared to STD; HIGH birds 15 % higher in BW compared to STD birds.

[2] Breast muscle weight included both the *P. Major* and *P. Minor*.

[3] Calculated ratio of keel length to thoracic width.

TABLE 5-5. Measurements taken from the *Pectoralis major* at sexual maturity, using digital image analysis [1], for female broiler breeders in LOW, STD or HIGH BW groups

Parameter	LOW	BW group [2] STD	HIGH	SEM	Probability
	------------------ Mean	------------------			
Whole breast measures [3]					
Area (cm^2)	263.1 ^{b}	274.5 ^{a}	279.2 ^{a}	3.5	0.0043
Length (cm) [4]	20.5	20.2	20.2	0.4	0.7982
Center length (cm)	15.4	15.6	15.7	0.1	0.0975
Half line (cm)	18.39 ^{b}	18.99 ^{a}	19.14 ^{a}	0.16	0.0022
Widest line (cm)	19.15 ^{b}	19.66 ^{a}	19.76 ^{a}	0.15	0.0121
Long slice measures [5]					
Length (cm)	22.42 ^{b}	23.08 ^{a}	23.45 ^{a}	0.19	0.0005
Thickest (cm)	2.55	2.62	2.70	0.06	0.1604
Middle (cm)	1.65	1.78	1.76	0.04	0.0926
Thinnest (cm)	1.04	1.06	1.04	0.03	0.8295
Wide slice measures [6]					
Area (cm^2)	19.74 ^{b}	22.06 ^{a}	21.80 ^{a}	0.40	0.0001
Length (cm)	11.00 ^{b}	11.68 ^{a}	11.30 ^{b}	0.14	0.0021
Outer (cm)	1.71	1.84	1.81	0.04	0.0691
Middle (cm)	1.86	1.85	1.78	0.05	0.4894
Inner (cm) [7]	1.95	2.01	1.97	0.04	0.6492

$^{a, b, c}$ Means within a row with no common superscript differ significantly at $P < 0.05$.

[1] Digital image analysis : using the software program Northern Exposure ® by Empix Imaging Inc., Mississauga, ON, Canada, L5L 5M6.

[2] BW : STD birds on target according to Arbor Acres Breeder Management Guide; LOW birds 15 % lower in BW compared to STD; HIGH birds 15 % higher in BW compared to STD birds.

[3] Whole Breast measures: length = average of longest lines from tip of shoulder to bottom of keel; widest = line perpendicular to keel at widest point of the breast; half = line perpendicular to keel at the midpoint of the breast.

[4] Average length of line 1 and 2 from the whole breast. Each line begins at the top of the shoulder and continues downwards to the keel.

[5] Long slice : 1 cm wide slice following line 1 of the whole breast. Transverse section of *P. major* taken from the left side of the muscle beginning at the top of the shoulder and continuing downwards to the keel.

[6] Wide slice : 1 cm wide slice following widest line. Transverse section of the *P. major* taken from the right beginning at the keel and continuing to the end of the muscle.

[7] Inner : innermost thickness towards the keel.

TABLE 5-6. Ovarian characteristics at sexual maturity for female broiler breeders in LOW, STD, or HIGH BW groups

	BW group[1]				
Parameter	LOW	STD	HIGH	SEM	Probability
	---------------- Mean -------------				
Reproductive Organs					
Ovary weight (g)	61.5^{b}	62.8^{ab}	64.5^{a}	1.1	0.0431
Ovary weight (%)	1.94	1.91	1.87	0.05	0.5851
Oviduct weight (g)	56.6	59.3	61.8	1.5	0.1382
Oviduct weight (%)	2.11^{a}	2.03^{ab}	1.95^{b}	0.03	0.0017
Stroma weight (g)	6.7	6.1	6.2	0.2	0.1962
Stroma weight (%)	0.22^{a}	0.19^{b}	0.19^{b}	0.0006	0.0001
Normal Ovarian Follicles					
SYF (#)[2]	9.8	8.8	8.7	0.5	0.2249
LYF (#)[3]	6.89^{b}	7.14^{ab}	7.58^{a}	0.17	0.0178
Atretic Ovarian Follicles					
Atretic SYF (#)	0.9	0.5	0.6	0.2	0.0882
Atretic LYF (#)	0.4	0.2	0.1	0.1	0.2085
LYF Parameters					
Total weight of LYF (g)	50.2^{b}	53.4^{ab}	55.1^{a}	1.5	0.0419
Unexplained POF	0.3	0.4	0.4	0.1	0.3457
F1 Weight (g)	12.3	12.6	12.2	0.2	0.3394
Mean Weight (g)	7.2	7.5	7.4	0.1	0.3878
Number in Multiple Sets[4]	2.30^{b}	2.61^{b}	3.42^{a}	0.26	0.0076
Percent in Multiple Sets (%)[4]	29.47^{b}	33.53^{b}	42.89^{a}	2.98	0.0045
Hierarchy Positions[5]	5.86	5.99	5.97	0.14	0.7757
Number of Hierarchies[6]	1.19^{b}	1.21^{b}	1.28^{a}	0.02	0.0157

[a, b, c] Means within a column with no common superscript differ significantly at $P < 0.05$.

[1] BW : STD birds on target according to Arbor Acres Breeder Management Guide; LOW birds 15 % lower in BW compared to STD; HIGH birds 15 % higher in BW compared to STD birds.

[2] SYF are 5 – 10 mm in diameter.

[3] LYF are > 10 mm in diameter.

[4] Follicles were paired if they differed by ≤ 1 g when F1 weight was > 3.0 g or if they differed by ≤ 0.5 g when F1 weight was < 3.0 g.

[5] Number of groups of follicles differed by 1 g when follicles were > 3.0 g or differed by 0.5 g when follicles were < 3.0 g.

[6] Hierarchies calculated from number of LYF / number of hierarchy positions.

TABLE 5-7. Growth rate of conformation measurements (mm / wk) from 18 wk of age to sexual maturity for female broiler breeders in LOW, STD, or HIGH BW groups

	BW group[1]				
Parameter	LOW	STD	HIGH	SEM	Probability
Shank length	104.56^{c}	106.10^{b}	107.94^{a}	0.34	0.0001
Gain[2]	0.52	0.54	0.59	0.02	0.2240
% Gain	0.50	0.51	0.55	0.02	0.2438
Keel length	145.93^{c}	150.43^{b}	153.16^{a}	0.48	0.0001
Gain	2.09^{a}	2.08^{a}	1.92^{b}	0.05	0.0193
% Gain	1.47^{a}	1.42^{a}	1.28^{b}	0.03	0.0760
Breast thickness[3]					
Upper part of muscle[4]	20.60^{b}	23.00^{a}	23.86^{a}	0.45	0.0001
Gain	1.28	1.49	1.40	0.13	0.4755
% Gain	7.56	7.18	6.35	0.58	0.3103
Lower part of muscle[5]	23.24	22.86	23.15	1.11	0.9640
Gain	3.50	1.58	1.53	1.25	0.4002
% Gain	17.00	7.82	7.60	5.18	0.2973
Thoracic width	69.29^{c}	72.38^{b}	75.60^{a}	0.34	0.0001
Gain	2.64	2.52	2.60	0.05	0.2334
% Gain	3.96^{a}	3.58^{b}	3.54^{b}	0.08	0.0001
Thoracic circumference	322.86^{c}	333.84^{b}	343.31^{a}	0.78	0.0001
Gain	5.78^{a}	5.16^{b}	4.95^{b}	0.14	0.0001
% Gain	1.83^{a}	1.58^{b}	1.47^{b}	0.04	0.0001

$^{a, b, c}$ Means within a row with no common superscript differ significantly at $P < 0.05$.

[1] BW : STD birds on target according to Arbor Acres Breeder Management Guide; LOW birds 15 % lower in BW compared to STD; HIGH birds 15 % higher in BW compared to STD birds.

[2] Gain : the total gain from 18 wk of age to SM.

[3] Breast thickness measured by ultrasound using Aloka ultrasound diagnostic equipment, Model SSD-500, Aloka Co. Ltd., Tokyo, Japan.

[4] Average of left and right ultrasound measurements on upper part of the breast muscle.

[5] Average of left and right ultrasound measurements on lower part of the breast muscle.

TABLE 5-8. Comb size measured from 18 wk of age to sexual maturity, and determined by digital image analysis [1], for female broiler breeders in BW and hatching treatments

	BW group [2]				Hatching Treatment [3]		
Comb Size	LOW	STD	HIGH	SEM	OASIS	CONTROL	SEM
Length (mm)	32.07 ^{c}	34.39 ^{b}	36.55 ^{a}	0.54	33.36 ^{b}	35.32 ^{a}	0.43
Gain [4]	2.96 ^{b}	3.16 ^{b}	3.64 ^{a}	0.09	3.11 ^{b}	3.40 ^{a}	0.08
% Gain	9.86 ^{b}	10.08 ^{b}	10.91 ^{a}	0.27	10.02	10.55	0.22
Height (mm)	12.90 ^{c}	14.71 ^{b}	15.87 ^{a}	0.32	14.00	14.98	0.26
Gain	1.81 ^{b}	2.03 ^{b}	2.16 ^{a}	0.10	1.95	2.05	0.08
% Gain	15.73	15.67	15.69	0.56	15.57	15.81	0.44
Area (mm^{2})	25.65 ^{c}	31.92 ^{b}	36.44 ^{a}	1.35	29.07 ^{b}	33.61 ^{a}	1.09
Gain	6.23 ^{c}	7.66 ^{b}	8.98 ^{a}	0.42	7.11 ^{b}	8.14 ^{a}	0.33
% Gain	29.82	31.32	32.10	1.02	30.72	31.44	0.81

^{a,b,c} Means within a row with no common superscript differ significantly at $P < 0.05$.

[1] Comb length, height and area measured by the digital image analysis software program Northern Exposure® by Empix Imaging Inc., Mississauga, ON, Canada, L5L 5M6.

[2] BW : STD birds on target according to Arbor Acres Breeder Management Guide; LOW birds 15 % lower in BW compared to STD; HIGH birds 15 % higher in BW compared to STD birds.

[3] OASIS chicks received Oasis ® hatching supplement during holding in chick boxes for 30 h prior to placement; CONTROL chicks received no hatching supplement during holding in chick boxes for 30 h prior to placement.

[4] Gain : the total gain from 18 wk of age to SM.

TABLE 5-9. The correlation between morphology measurements and the average number of days it took for female broiler breeders in LOW, STD or HIGH BW groups to reach sexual maturity

	Body Weight	Shank Length	Keel Length	Thoracic Width	L:W[1] Ratio	Thoracic Circum.	Comb Size[2]		
Parameter							Length	Height	Area
Age (wk)									
18	-0.35[3]	0.008	-0.18	-0.28	0.11	-0.26	-0.24	-0.25	-0.23
	0.0001[4]	0.9080	0.0066	0.0001	0.1068	0.0001	0.0003	0.0001	0.0003
19	-0.37	0.03	-0.20	-0.26	0.16	-0.31	-0.26	-0.29	-0.30
	0.0001	0.6115	0.0023	0.0001	0.0124	0.0001	0.0001	0.0001	0.0001
20	-0.37	0.25	-0.20	-0.27	0.18	-0.29	-0.32	-0.35	-0.35
	0.0001	0.7001	0.0017	0.0001	0.0058	0.0001	0.0001	0.0001	0.0001
21	-0.36	0.02	-0.19	-0.33	0.24	-0.29	-0.35	-0.40	-0.37
	0.0001	0.7108	0.0030	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001
22	-0.36	0.02	-0.17	-0.29	0.20	-0.30	-0.42	-0.42	-0.42
	0.0001	0.8113	0.0106	0.0001	0.0017	0.0001	0.0001	0.0001	0.0001
23	-0.36	0.01	-0.16	-0.30	0.23	-0.30	-0.44	-0.44	-0.43
	0.0001	0.8520	0.0148	0.0001	0.0004	0.0001	0.0001	0.0001	0.0001
24	-0.35	-0.03	-0.13	-0.24	0.16	-0.31	-0.40	-0.45	-0.42
	0.0001	0.7020	0.0395	0.0003	0.0138	0.0001	0.0001	0.0001	0.0001
25	-0.33	-0.03	-0.03	-0.17	0.15	-0.27	-0.32	-0.40	-0.33
	0.0001	0.7324	0.6597	0.0112	0.0249	0.0001	0.0001	0.0001	0.0001
26	-0.27	-0.02	0.03	-0.17	0.19	-0.22	-0.32	-0.42	-0.37
	0.0001	0.7576	0.6922	0.0281	0.0187	0.0060	0.0001	0.0001	0.0001
27	-0.26	-0.08	0.18	-0.05	0.05	-0.14	-0.44	-0.27	-0.45
	0.0245	0.4682	0.1080	0.6541	0.6361	0.7884	0.0001	0.0141	0.0001
28	-0.16	0.07	0.23	-0.12	0.26	-0.05	-0.33	-0.40	-0.37
	0.4262	0.7333	0.2377	0.5266	0.1692	0.4064	0.0839	0.0349	0.0507
29	-0.14	0.56	0.52	0.19	0.27	0.26	-0.53	-0.54	-0.59
	0.7499	0.0556	0.0806	0.5588	0.4148	0.4064	0.0758	0.0680	0.0420

[1] Calculated ratio of keel length to thoracic width.

[2] Comb length, height and area measured by the digital image analysis software program Northern Exposure® by Empix Imaging Inc., Mississauga, ON, Canada, L5L 5M6.

[3] Correlation coefficient.

[4] Probability is indicated immediately below the correlation coefficient.

Table 5-10. Mean values for bird conformation, breast muscle thickness, comb size, plasma estradiol-17β concentration and plasma lipid concentration from broiler breeder pullets in the LOW [1] BW treatment

	Age (wk)													
	18	19	20	21	22 [2]	23	24	25	26	27	28	29	30	31
Bird conformation (mm)														
Shank length	102.1	103.3	103.8	104.1	104.5	104.9	105.3	105.7	106.3	107.1	107.4	108.0	110.5	111.0
Keel length	135.9	138.6	141.2	142.9	145.8	147.8	149.6	151.7	153.7	155.6	157.7	157.5	163.0	163.0
Thoracic width	58.4	60.5	61.5	63.3	67.7	69.9	75.0	77.6	80.1	82.1	83.5	85.8	88.0	88.0
Thoracic circumference	296.3	304.3	312.3	318.6	322.5	326.7	330.5	334.4	341.5	348.3	348.3	359.9	366.0	367.0
Breast muscle (mm)														
Upper thickness	N/A	14.3	15.6	17.4	19.3	21.7	22.5	25.4	23.3	24.7	27.2	N/A	N/A	N/A
Lower thickness	N/A	14.5	14.8	17.0	19.5	22.6	23.3	24.6	31.9	25.4	27.8	N/A	N/A	N/A
Comb size (mm)														
Length	21.5	22.8	24.2	25.8	29.9	33.2	37.1	39.6	43.6	47.9	44.6	48.5	43.8	46.3
Height	6.7	7.5	8.4	9.4	11.8	13.5	15.3	16.9	19.7	22.5	20.7	22.5	20.8	21.3
Area	7.5	8.9	10.7	12.3	19.4	24.6	32.2	38.4	50.2	62.7	54.4	63.6	49.2	53.3
Plasma estradiol (pg/mL)	N/A	16.8	14.5	19.8	20.8	69.8	94.8	121.6	148.4	194.4	205.8	175.6	N/A	N/A
Plasma lipid (mg/mL)	N/A	3.9	4.0	4.7	4.9	5.2	4.4	6.1	9.1	15.3	11.0	N/A	N/A	N/A

[1] LOW : birds were fed to achieve 15 % lower BW than STD birds fed according to the Arbor Acres Breeder Management Guide.

[2] 22 wk: photostimulation from 8 h to 15 h of light.

Table 5-11. Mean values for bird conformation, breast muscle thickness, comb size, plasma estradiol-17β concentration and plasma lipid concentration from broiler breeder pullets in the STD [1] BW treatment

	Age (wk)											
	18	19	20	21	22 [2]	23	24	25	26	27	28	29
Bird conformation (mm)												
Shank length	103.7	104.9	105.4	105.8	106.2	106.5	106.9	107.4	108.1	109.3	108.9	109.3
Keel length	140.5	144.8	146.6	148.6	150.9	152.8	154.3	156.0	157.7	159.9	162.2	164.3
Thoracic width	63.1	64.8	65.7	67.2	71.0	73.7	78.7	81.3	84.0	85.3	85.9	90.8
Thoracic circumference	311.4	318.2	325.2	330.8	335.3	338.8	341.9	345.2	352.0	358.1	363.9	376.0
Breast muscle (mm)												
Upper thickness	N/A	17.6	18.7	19.6	22.8	23.9	25.7	27.2	27.6	27.1	27.4	N/A
Lower thickness	N/A	16.7	18.6	19.8	22.5	23.8	25.3	26.2	30.6	26.4	27.6	N/A
Comb size (mm)												
Length	22.9	24.8	26.6	28.3	34.3	37.8	40.8	43.6	46.9	49.8	50.6	53.2
Height	7.9	8.8	10.0	11.3	14.7	16.3	18.1	20.0	22.1	28.2	25.6	26.9
Area	9.4	11.2	14.5	17.4	28.7	35.4	43.7	52.8	63.4	75.5	75.6	93.2
Plasma estradiol (pg/mL)	N/A	24.4	20.6	28.3	22.8	81.7	126.1	156.0	169.4	151.5	186.5	N/A
Plasma lipid (mg/mL)	N/A	3.7	4.5	4.7	4.2	4.4	4.9	8.6	12.3	14.2	N/A	N/A

[1] STD : birds were fed to target BW according to the Arbor Acres Breeder Management Guide.

[2] 22 wk: photostimulation from 8 h to 15 h of light.

Table 5-12. Mean values for bird conformation, breast muscle, comb size, plasma estradiol-17β concentration and plasma lipid concentration from broiler breeder pullets in the HIGH [1] BW treatment

	Age (wk)									
	18	19	20	21	22 [2]	23	24	25	26	27
Bird conformation (mm)										
Shank length	105.6	106.7	107.2	107.6	108.1	108.5	109.4	108.9	110.4	111.1
Keel length	144.5	148.7	150.5	152.3	154.2	155.5	156.7	159.4	161.0	162.8
Thoracic width	66.3	68.8	70.3	71.5	75.1	77.5	82.4	85.0	86.4	87.8
Thoracic circumference	322.9	330.2	336.4	341.4	345.6	348.7	352.2	356.0	362.0	366.1
Breast muscle (mm)										
Upper thickness	N/A	19.4	20.0	20.7	24.1	25.2	27.4	28.7	28.6	27.2
Lower thickness	N/A	18.0	18.5	20.0	23.2	24.6	26.6	27.6	36.5	26.8
Comb size (mm)										
Length	24.2	25.9	28.5	31.2	37.3	41.2	45.0	47.0	52.4	56.7
Height	8.6	9.8	11.4	12.8	16.4	18.4	20.5	21.9	24.9	27.5
Area	11.1	13.5	17.3	21.6	34.5	43.0	54.1	61.8	78.9	91.6
Plasma estradiol (pg/mL)	N/A	29.0	29.6	33.5	29.2	88.9	147.6	179.5	212.5	237.0
Plasma lipid (mg/mL)	N/A	3.8	3.7	3.3	3.6	5.4	8.0	17.2	9.5	6.7

[1] HIGH : birds were fed to achieve 15 % heavier BW than STD birds fed according to the Arbor Acres Breeder Management Guide.

[2] 22 wk: photostimulation from 8 h to 15 h of light.

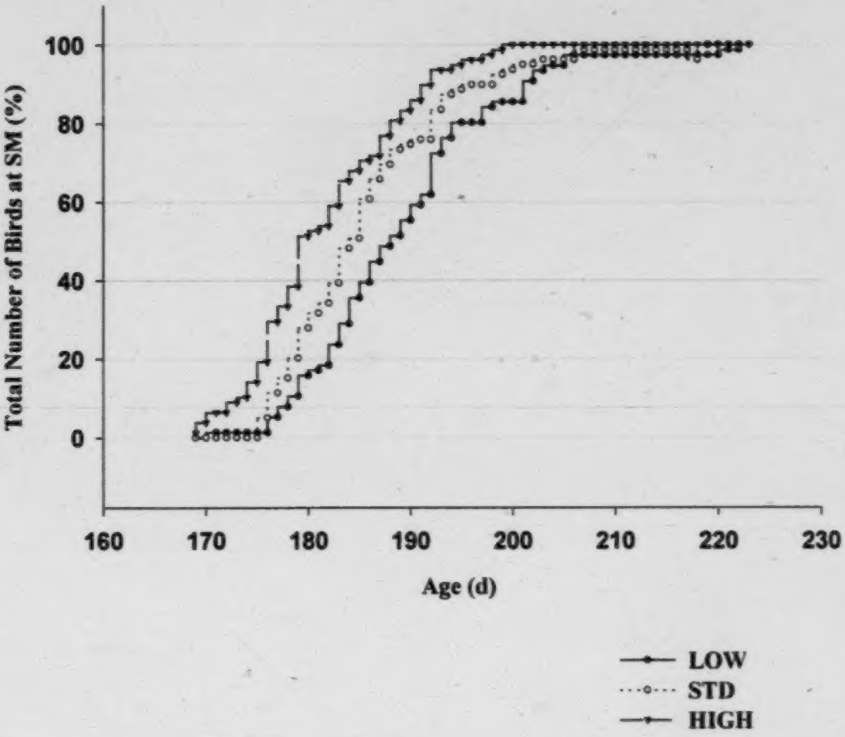

FIGURE 5-1. Proportion of female broiler breeders at sexual maturity (%) in LOW, STD, or HIGH BW groups (n : LOW = 76, STD = 80, and HIGH = 78). Birds were photostimulated at 22 wk of age (140 d). HIGH birds came into sexual maturity sooner (HIGH = 182.5 d; STD = 186.4 d and LOW = 190.1 d of age). Bars indicate SEM.

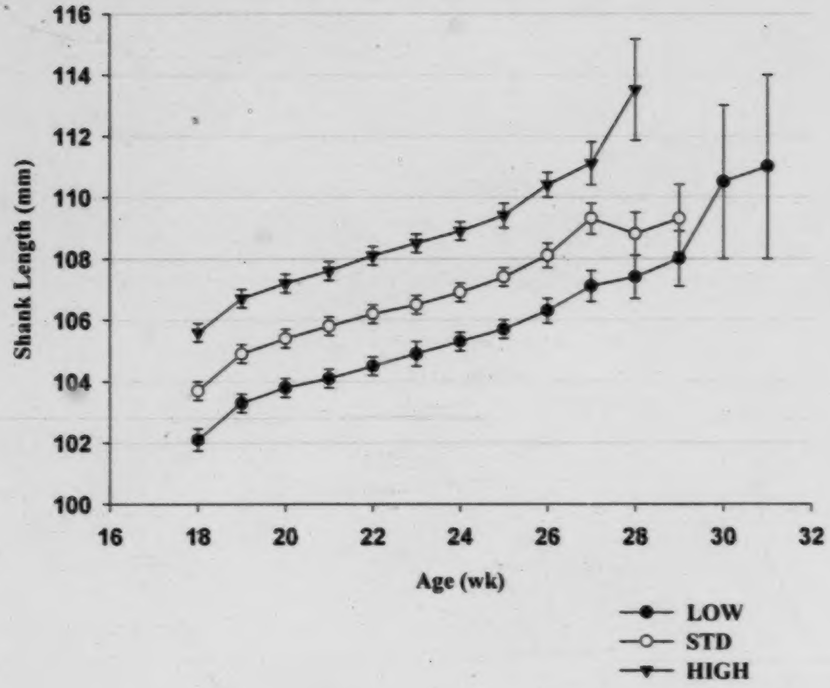

FIGURE 5-2. Average weekly shank length (mm) of female broiler breeders in LOW, STD, or HIGH BW groups (n : LOW = 76, STD = 80, and HIGH = 78). Birds per treatment group decreased to < 10 at HIGH = 28 wk; STD = 28 wk and LOW = 29 wk. Values after 25 wk of age represent birds that remained in the experiment until sexual maturity. Bars indicate SEM.

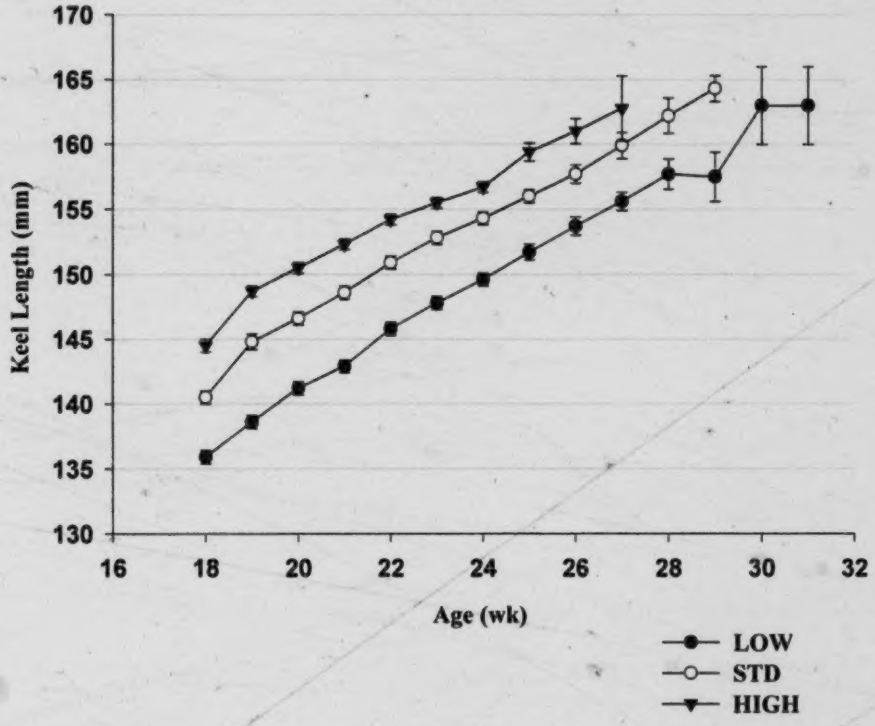

FIGURE 5-3. Average weekly keel length (mm) for female broiler breeders in a LOW, STD, or HIGH BW groups (n : LOW = 76, STD = 80, and HIGH = 78). Birds per treatment group decreased to < 10 at HIGH = 27 wk, STD = 28 wk, and LOW = 29 wk. Values after 25 wk of age represent birds that remained in the experiment until SM. Bars indicate SEM.

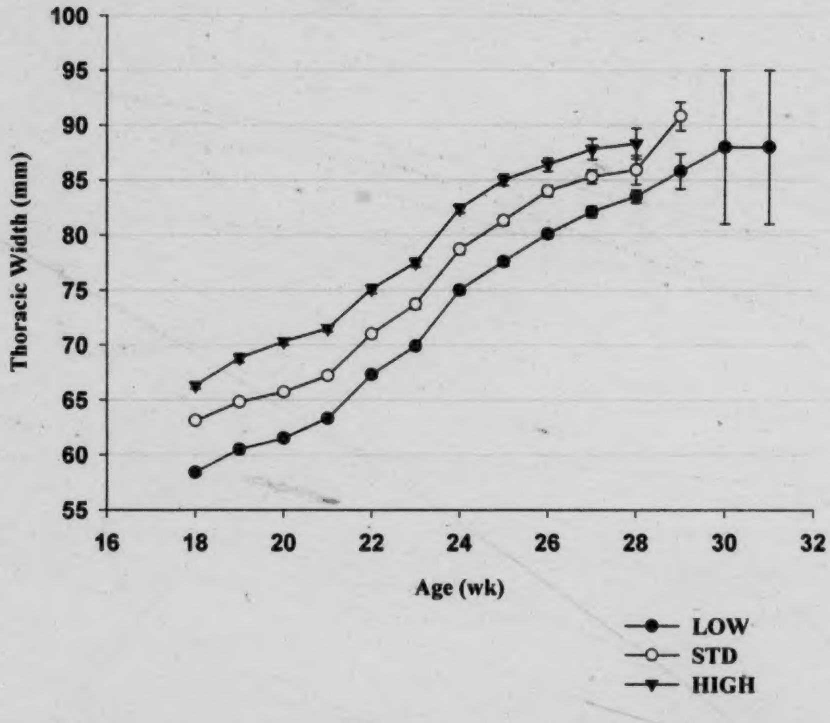

FIGURE 5-4. Average weekly thoracic width (mm) for female broiler breeders in LOW, STD, or HIGH BW groups (n : LOW = 76, STD = 80, and HIGH = 78). Birds per treatment group decreased to < 10 at HIGH = 27 wk, STD = 28 wk and LOW = 29 wk. Values after 25 wk of age represent birds that remained in the experiment until sexual maturity. Bars indicate SEM.

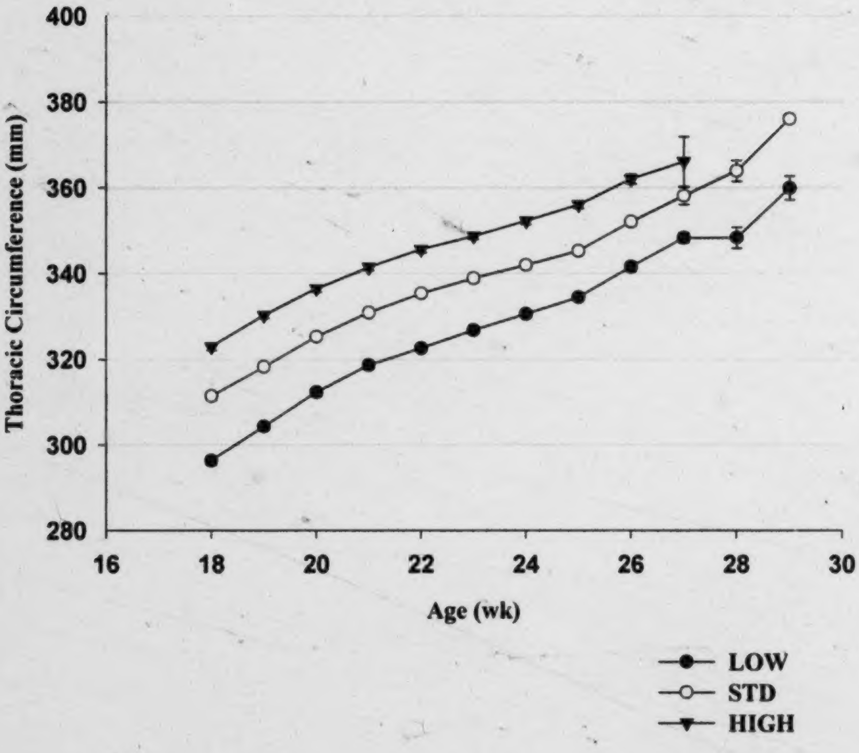

FIGURE 5-5. Average weekly thoracic circumference for female broiler breeders in LOW, STD or HIGH BW groups (n : LOW = 76, STD = 80, and HIGH = 78). Bird numbers per treatment group decreased to < 10 birds per treatment at HIGH = 28 wk; STD = 28 wk and LOW = 29 wk). Values after 25 wk of age represent birds that were not yet sexually mature. Bars indicate SEM._

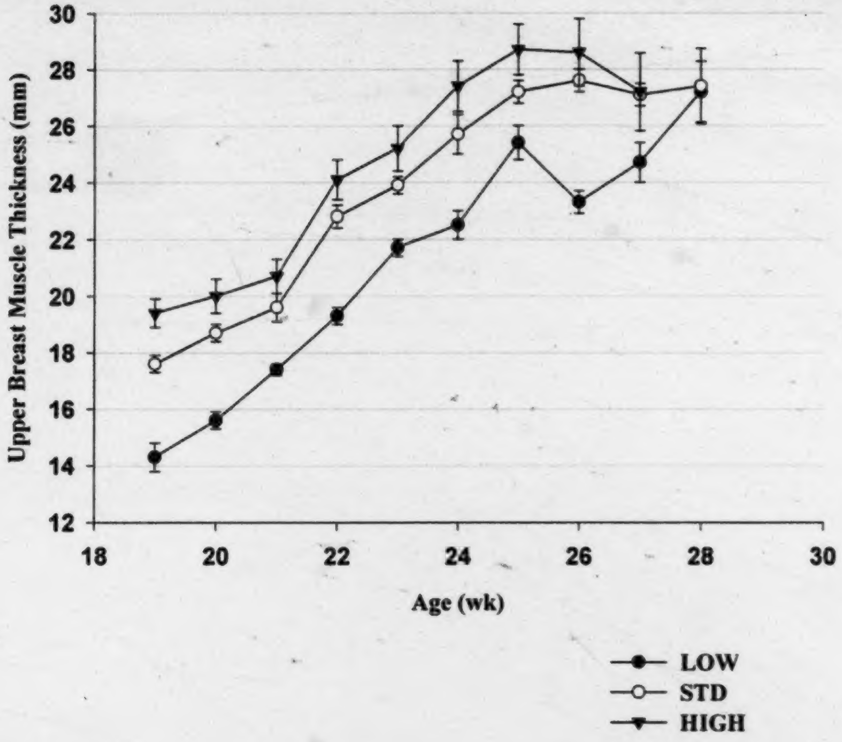

FIGURE 5-6. Average weekly breast muscle thickness (mm) on the upper section of the breast for female broiler breeders in LOW, STD, or HIGH BW groups (n : LOW = 76, STD = 80, and HIGH = 78). Breast muscle thickness was measured by ultrasound (n = 12 birds / group). Bird numbers per treatment groups decreased to < 10 birds at HIGH = 26 wk, STD = 26 wk and LOW = 27 wk . Values after 25 wk of age indicate remaining birds that were not yet sexually mature. Bars indicate SEM.

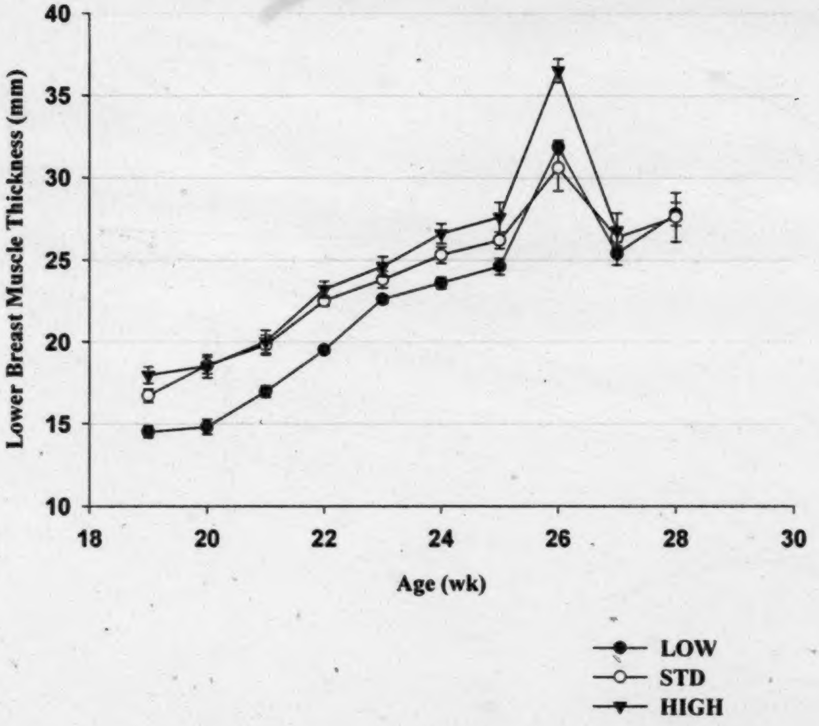

FIGURE 5-7. Average weekly breast muscle thickness (mm) on the lower section of the breast for female broiler breeders in LOW, STD, or HIGH BW groups (n : LOW = 76, STD = 80, and HIGH = 78). Breast muscle thickness was measured by ultrasound (n = 12 birds / group). Bird numbers per treatment groups decreased to < 10 birds at HIGH = 26 wk, STD = 26 wk and LOW = 27 wk . Values after 25 wk of age indicate remaining birds that were not yet sexually mature.Bars indicate SEM.

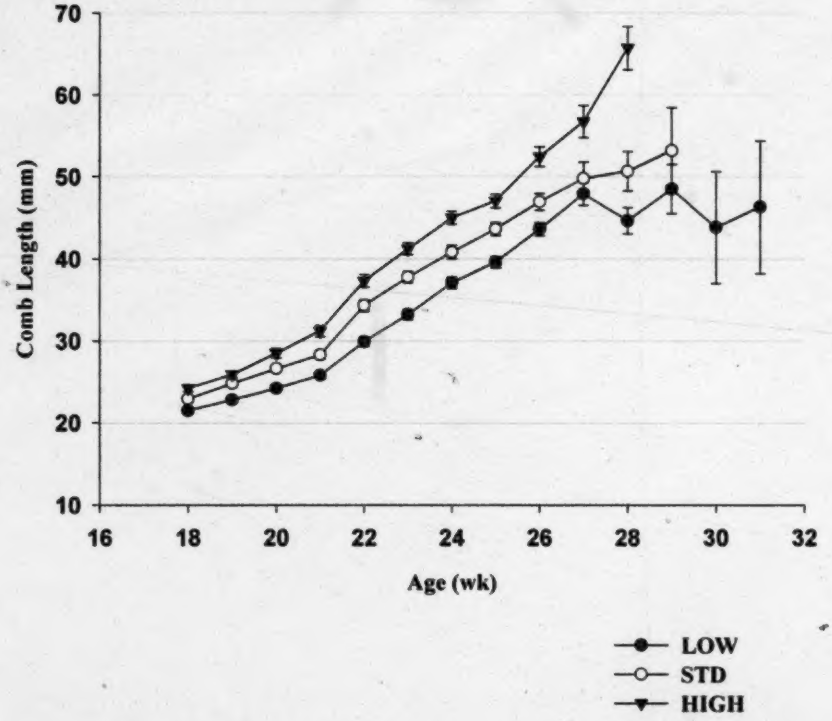

FIGURE 5-8. Average weekly comb length (mm) for female broiler breeders in LOW, STD, or HIGH BW groups (n : LOW = 76, STD = 80, and HIGH = 78). Bird numbers per treatment group decreased to < 10 birds per treatment at HIGH = 28 wk; STD = 28 wk and LOW = 29 wk). Values after 25 wk of age represent birds that were not yet sexually mature. Bars indicate SEM.

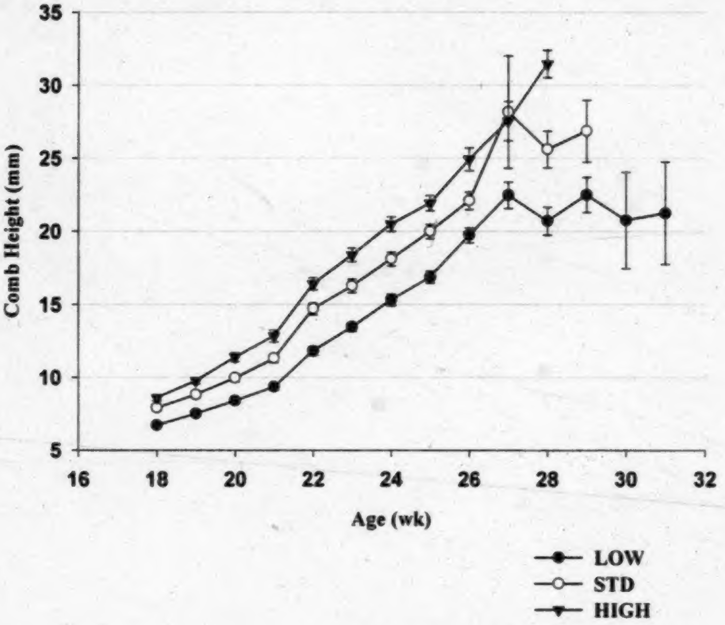

FIGURE 5-9. Average weekly comb height (mm) for female broiler breeders in LOW, STD, or HIGH BW groups (n : LOW = 76, STD = 80, and HIGH = 78). Bird numbers per treatment group decreased to < 10 birds per treatment at HIGH = 28 wk; STD = 28 wk and LOW = 29 wk). Values after 25 wk of age represent birds that were not yet sexually mature. Bars indicate SEM.

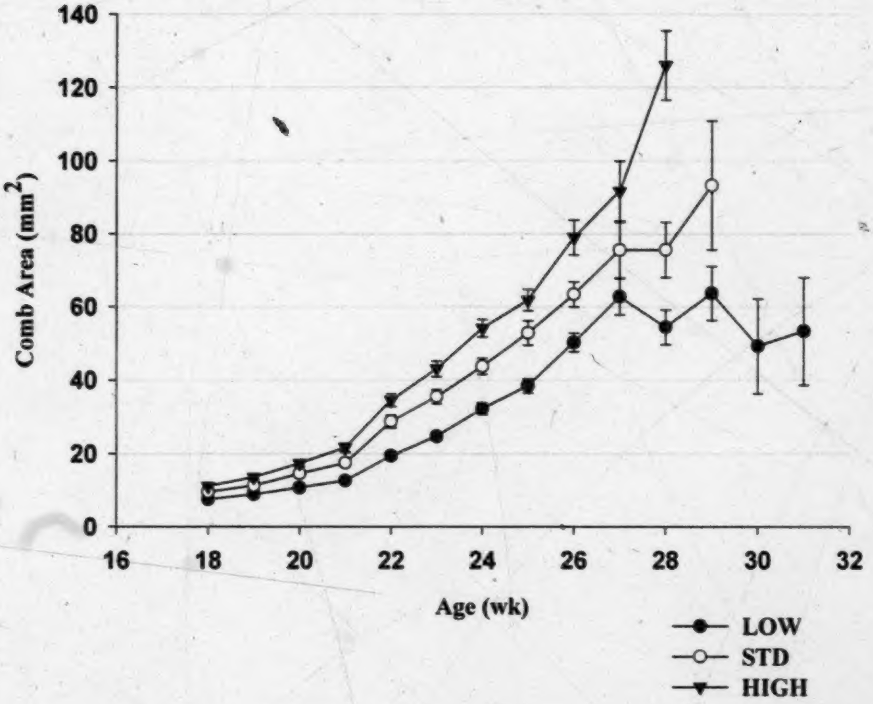

FIGURE 5-10. Average weekly comb area (mm^2) for female broiler breeders in LOW, STD, or HIGH BW groups (n : LOW = 76, STD = 80, and HIGH = 78). Bird numbers per treatment group decreased to < 10 birds per treatment at HIGH = 28 wk; STD = 28 wk and LOW = 29 wk). Values after 25 wk of age represent birds that were not yet sexually mature. Bars indicate SEM.

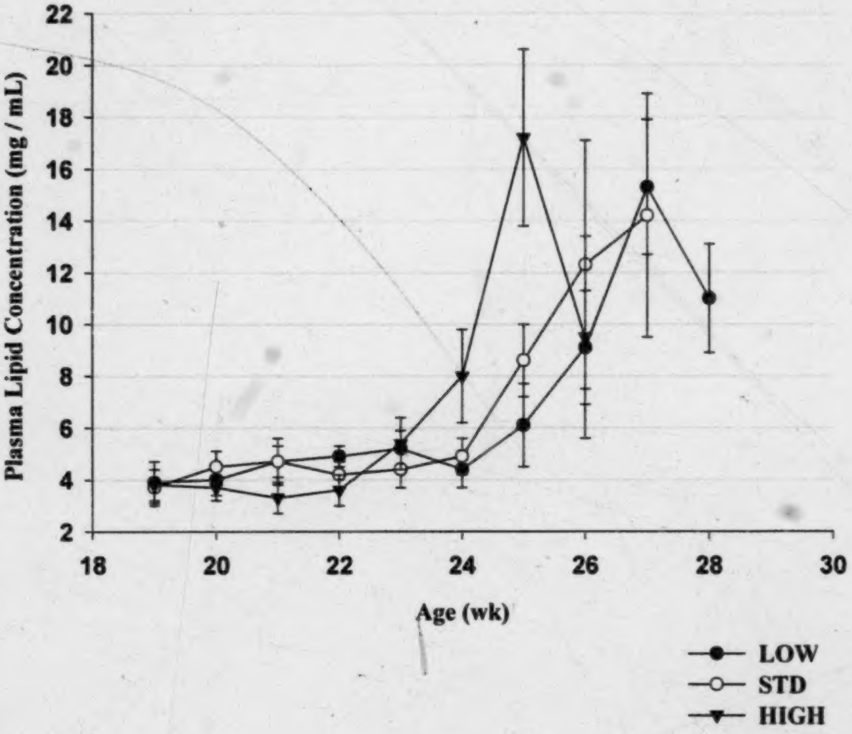

FIGURE 5-11. Average weekly plasma lipid concentration (mg / mL) for female broiler breeders in LOW, STD, or HIGH BW groups (n = 12 birds / group). Birds per treatment group decreased to < 10 at HIGH = 26 wk, STD = 26 wk and LOW = 27 wk. Values after 25 wk of age represent birds that were not yet sexually mature. Bars indicate SEM.

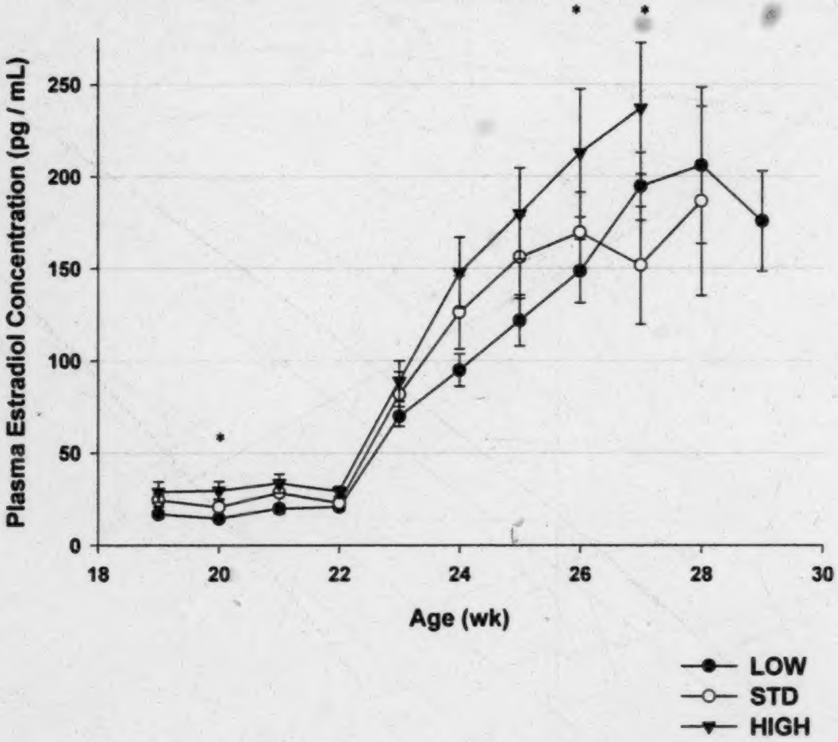

FIGURE 5-12. Average weekly plasma estradiol-17β concentration (pg / mL) for female broiler breeders in LOW, STD, or HIGH BW groups (n = 12 birds / group). Birds per treatment group decreased to < 10 at HIGH = 26 wk, STD = 26 wk and LOW = 27 wk. Significance between the BW treatments is shown by * ($P < 0.05$). Values after 25 wk of age represent birds that were not yet sexually mature. Bars indicate SEM.

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6.0 GENERAL DISCUSSION AND CONCLUSIONS

Broiler breeder producers face several key management issues. Reproductive efficiency tends to decrease near the end of the egg production cycle. The reason older birds are less efficient egg layers is because follicular maturation slows down with increasing age. Hens at peak production have 24 to 25 h intervals between ovulations (Etches, 1996). However, older hens require an additional 15 h compared to younger hens, before mature follicles are competent to ovulate (Shanawany, 1992). Follicular growth decreases as a result of reduced LH pulses from the pituitary gland (Williams and Sharp, 1978a) and mature follicles can only successfully ovulate in the presence of a LH surge (Etches, 1996). Older hens tend to produce heavier ovarian follicles because these follicles take longer to mature (Williams and Sharp, 1978b), and this results in heavier egg weights. Currently, hatcheries in Canada will not accept breeder eggs that are less than 52 g. Extra large eggs are not acceptable because they may not always fit in commercial incubating trays. One research focus has examined the effects of ahemeral day lengths on reproductive function in aims to enhance reproduction with chronological age, without increasing egg weight. In Chapter 2, hens on a 28 h day (15 L: 13 D) laid eggs that were nearly 2 g heavier than eggs laid from hens under 24 h days, and agrees with data from other research (Leeson et al., 1979; Nordstrom, 1982). Reproductive function also suffered with the use of a 28 h day. Ahemeral birds had a smaller ovary, lower egg production rates, higher amounts of defective eggs, lower F1 follicle weights, and poorer eggshell quality. The ovary may be less sensitive to LH pulses when the day length is changed at an older age (Morris, 1978).

Currently, the reproductive cycle in broiler breeders is short-lived. Lower egg output from older birds can lower farm revenue and increase flock turnover rate. Ultimately, the broiler breeder producer is at an economic loss because higher labor costs are associated with managing a new flock. Future research in this area would be beneficial in determining the most appropriate age where an ahemeral day length would best improve ovarian function. Shanawany et al. (1993)

noted that breeders respond better to ahemeral lighting when their egg production rates are greater than six eggs per sequence. Additional experiments could be designed with the intent of examining the effect of implementing ahemeral lighting after peak production and continuing for a longer than an 8 wk period.

Hatcheries in Alberta have begun to provide a nutrient supplement for broiler chicks at hatching. Long transportation times seem to dehydrate broiler chicks and cause a poor start in life (Sunny Mak, Lilydale Hatchery, 7503-127 Ave, Edmonton, Canada, Personal Communication, 2002). Most of the published literature has examined hatching delays in broiler chickens and found that a lack of feed and water decreased market BW by 10 % (40 d of age) (Pinchasov and Noy, 1993). The current research associated with broiler chickens is not always applicable to broiler breeders, even though both species are meat-type. Broiler chickens reach market weight between 6 to 8 wk, whereas the broiler breeder production cycle is as long as 60 wk. Studies that examine the effects of exogenous nutrient intake in broiler breeders would be more easily applied to these birds.

A majority of the broiler breeder chicks placed on Canadian farms must travel from pedigree hatcheries within the United States. These distances can be up to 48 h longer than the distances that broiler chicks travel. It is surprising that little is known about the effect of hatching supplements on the subsequent growth of broiler breeder chicks. The research in Chapter 3 discussed the advantages of administering a hatching supplement to breeder chicks that had a 30 h placement delay. Body weight gains and absolute BW were best improved up to 4 wk of age, and diminished by 18 wk of age. Broiler breeder producers have many products to choose from which promise improved feed conversion, egg production, or prevent diseases. Testing helps to "guarantee" a safe product with good results. However, companies advertising a safe product are biased from testing their own product. Scientific research in this area can help provide broiler producers with a more objective view when selecting products for their flocks. So far, one other study by Noy and Sklan (1999) has used the Oasis® product but this was tested on broiler chickens and turkey poults and not on broiler breeders. At market age, breast muscle mass increased by 10 %, a result that reflects better economic value from meat-type birds. Scientists have repeatedly demonstrated that nutrient supplementation had positive effects on subsequent growth in broilers (Sklan et al., 2000), turkeys (Noy and Sklan, 1999) and now in broiler breeders (Chapter 3). Less is known about the mechanisms behind these results. Some researchers suggested the hypothesis that hatching supplements increase yolk utilization (Pinchasov and Noy, 1993) which causes the gastrointestinal tract to mature at a faster rate than in chicks held without feed, water, or nutrient supplement (Noy and Sklan, 1997). The next step in this research would be to test this hypothesis when the Oasis ® product is fed to breeder chicks with long post hatch delays.

Commercial broiler breeders are reproductively competent between 24 and 25 wk of age because of a photostimulatory cue approximately 2 wk previous to sexual maturity. During the onset of sexual maturation, it was expected that nutrient intake would shift from growth to reproduction, as others have stated. Breast muscle growth has been shown to slow down as reproduction commenced (Joseph, 2000). In addition, the degree of fatness in a breeder hen increases as she chronologically ages (Robinson et al., 1996). These findings may be relevant when birds are fed according to target levels. However, birds receiving less than target levels of feed are at a disadvantage to other flock members. The results from Chapter 4 indicated that birds with BW 15 % lower than the levels recommended from the Arbor Acres Classic Flock Records (Anonymous, 2000), had thinner and narrower breast muscles. Low weight birds were most likely growing breast muscle and reproductive organs after photostimulation at 22 wk of age, as was indicated by a higher rate of gain in carcass conformation from 18 wk of age to sexual maturity (Chapter 5). The disadvantages were apparent because low weight birds took longer to sexually mature, had lower ovary weights and a lower number of ovulating follicles.

One of the biggest reproductive issues facing breeder producers is determining a similar time of sexual maturation in their flocks. Peak egg production rates are higher when more birds reach sexual maturity at the same time (Hudson et al., 2001). Chapter 5 confirmed that varying BW had an effect on the timing of sexual maturity in breeder females. Other research suggested that the time of sexual maturity is affected by a "threshold" degree of body fatness (Bornstein et al., 1984) or BW (Brody et al., 1984). This finding was challenged by Dunnington and Siegel (1984) who found that Leghorn pullets had either the expected chronological age at sexual maturity or the minimum BW requirements, but not both. Research published 15 years later indicated that broiler breeder of varying strain were sexually mature at different times. In addition, *ad libitum* or restricted feeding had no impact on the timing of sexual maturity in some strains, suggesting that sexual maturation is governed by other phenomena (Robinson et al., 1999). Recently published research has focussed more on ovarian endocrinology to help understand the timing of sexual maturation. The hypothalamus is the control center for initiating and regulating reproductive hormones in the hen. Maturation of this organ must take place before the onset of reproductive maturity (Renema et al., 1999b; Robinson et al., 2001).

It is difficult to determine or predict sexual maturity in broiler breeder females. Research has focussed on external cues such as monitoring comb growth because comb size and circulating plasma estradiol concentrations were strongly related to each another (Eitan et al., 1998; Joseph et al., 2001). Currently in Alberta, broiler breeder producers manage birds based on average flock weights rather than allocating feed based on physical attributes such as comb size or degree of breast muscle fleshing. Monitoring the growth of these characteristics could help breeder producers identify the optimal time for a photostimulatory cue.

Data from Chapter 5 indicated that birds with LOW BW were not fleshed as well as STD or HIGH BW birds. Pullets with LOW BW had small conformation, thin breast muscle, small combs, and low plasma estradiol-17β concentration when they were photostimulated at 22 wk of age. The time of photostimulation did not cause birds to limit breast muscle growth and commence reproductive growth. Muscle and reproductive growth were most likely occurring simultaneously in pullets with LOW BW. Social dominance displayed by birds in the same flock negatively affect BW uniformity (Leeson and Summers, 1979). Aggressive feeding behavior is associated with heavier birds that tend to dominate during feed clean up time. Broiler breeder producers can circumvent this problem by sorting their pullets before photostimulation. Large framed and muscled birds can be sorted out of the flock and fed separately. Smaller birds would then have a chance to catch up in their body development before photostimulation. Broiler breeder producers would benefit from feed allocation guidelines that not only list weekly target BW, but also fleshing scores and skeletal frame size measurements. Proper information from a combination of factors, including target BW, can help fine-tune feed allocation and optimal timing of photostimulation.

Broiler breeder companies will continue to introduce new strains to the poultry industry. These strains will most likely promise to be more efficient in both reproduction and carcass traits. However, the challenge in optimizing reproductive traits while controlling BW has been long standing. In the future, breeder companies will most likely aim to select parent stock that generate broiler chicks that can grow to market age in less than 40 d. However, the inverse relationship between growth and reproduction (Robinson and Robinson, 1991; Renema et al., 1999b; Yu et al., 1992) means that reproductive management for future generations of broiler breeders will become increasingly more difficult. In Canada, broiler breeder producers are continually faced with the challenges of managing these new strains. Successful management of their flocks is reflected by the quantity of healthy and saleable chicks. Management practices that were successful in the past may not be as effective when new strains are introduced. Scientific research can acquire meaningful knowledge of broiler breeder reproduction and help provide economic benefits for the producer.

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